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A handbook of rocks : for use without the microscope

A

HANDBOOK OF ROCKS

FOR USE

WITHOUT THE MICROSCOPE.

BY

JAMES FURMAN KEMP, E.M., D.Sc.,

PROFESSOR OF GEOLOGY IN THE SCHOOL OF MINES, COLUMBIA UNIVERSITY,
NEW YORK.

WITH A

GLOSSARY OF THE NAMES OF ROCKS

AND OF OTHER

LITHOLOGICAL TERMS.

FIFTH EDITION, REVISED.

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PREFACE.

The clear presentation of the subject of rocks to beginners is not an especially simple undertaking. The series of objects is extremely diverse, and many unrelated processes are involved in their production. In order not to confuse and bewilder students, the teacher must emphasize the intelligible points and the recognizable characters, avoiding alike distinctions that have their chief foundations in past misconceptions, such as the time element in the classification of igneous rocks, and that require microscopic study to substantiate them. In the following pages the attempt has been made to avoid these difficulties, and only to mention and emphasize the characters which a beginner, properly equipped with the necessary preliminary training in mineralogy, can observe and grasp.

Some years of annually going over this ground have convinced the writer that for this purpose we are not likely to reach a more serviceable, fundamental classification than the time-honored one of Igneous, Aqueous (or Sedimentary) and Metamorphic rocks. They furnish not alone convenient central groups, but also prepare the student for subsequent geological reading. With the Aqueous have been placed the Eolian as a similar, although very minor division, so that fire, water and air, the ancient elementary agents, are emphasized in their work upon the earth, and the fundamental classification is based, as it should be, on method of origin. The only illogical step involved is the placing of the breccias together with the sediments, but breccias are so subordinate and go so conveniently with conglomerates, that it has been done.

The igneous rocks are the ones which present the greatest difficulties to the learner. In the following pages, after a preliminary exposition of principles, the very minor group of the volcanic glasses is first taken up, because it is the simplest and because it illustrates cooling from fusion most forcibly. Passing then through the felsitic and porphyritic to the granitoid textures, rocks of in-

creasing complexity are one after another attacked. Analyses have been freely used to illustrate the chemical differences of magmas, because in no other way can the varieties be fundamentally described. Within fairly narrow limits the chemical composition of the magma establishes the mineralogy of the rock.

The Aqueous and Eolian rocks are not difficult to understand. The metamorphic are in many respects the most obscure of all, but it is hoped that enough varieties have been selected and emphasized to serve for field use and for the reasonably close determination of the great majority of those that will be met in Nature.

Many names will be encountered in geological reading that are not mentioned in the book proper. To explain them and to avoid confusing the main text with unessential matter, they have been compiled in a Glossary. Practically all the names for rocks will be found there, and some related, geological terms. The chief guide in its preparation has been the index of Zirkel's great *Lehrbuch der Petrographie*, but not a few American terms are introduced, which are not in it nor in Loewinson-Lessing's *Petrographisches Lexikon*, to which the writer is also greatly indebted. Other works, English, French and American, have likewise been at hand. One only needs to compile a glossary to appreciate what numbers of unnecessary and ill-advised names for rocks burden this unfortunate branch of science, and to convince one that the philological petrographer comes near to being the enemy of his kind.

So far as possible, technical words of classical derivation have been avoided in the main work in favor of simple English, and for the rocks described, American types have been especially sought with which to illustrate the different species, because they are more significant and accessible to readers on this side of the ocean. The text, except the glossary, appeared as a series of papers in the *School of Mines Quarterly* during 1895–96. J. F. K.

AUGUST, 1896.

NOTE TO THE SECOND EDITION.

In the preparation of the second edition, but little change has been made in the main text. The Glossary has, however, been rewritten and brought up to date. J. F. K.

DECEMBER, 1899.

PREFACE TO THE THIRD EDITION.

Several important changes have been introduced in the present edition, chiefly in connection with the igneous rocks. The composition of the minerals entering into them has been more fully stated, graphic formulas being employed where they seemed desirable. The ingenious star-shaped diagrams which were first used by W. C. Broegger for single analyses and subsequently employed by W. H. Hobbs for composite groups, have been adapted to the analyses here selected and have been given under each important division of the igneous rocks. They present characteristic pictures of chemical composition which are well adapted to emphasize this important feature for beginners. Whenever, in an analysis, ferrous iron has not been separately determined, it has been necessary to assume a value for it on the basis of related analyses, but experiments with varying values have shown that within the limits set by the total iron oxides, the variation in the general shape of the figure is scarcely appreciable.

In the description of textures and their development much greater stress is laid than formerly upon the geological occurrence of the rock masses. The several forms, dikes, sheets, laccoliths, etc., have therefore been illustrated by cuts and in the table of classification, p. 23, they have been introduced in a separate column. The igneous rocks have also been treated in a slightly different way. Thus, having established a series of analyses characteristic of a certain group, as for instance the rhyolites and granites, this magma is followed through the several textures from the products of a quick chill to those of slow and deep-seated cooling. In nearly all cases four stages are emphasized and a uniform nomenclature is employed. Thus we have the Rhyolites, Rhyolite-porphyries, Granite-porphyries, Granite, and similarly for all the others. The diabases present the one exception to this uniform treatment. In developing the above plan an old and widely employed nomenclature has been used, which experience of some

years in the class-room and laboratory leads the writer to believe, has distinct advantages.

The matter relating to the sedimentary and metamorphic rocks has not been essentially changed. A chapter has been added on the recasting of analyses of igneous rocks, which may serve as an introduction to the Quantitative Classification of Cross, Iddings, Pirsson and Washington, the latter being too complicated for an elementary book. Finally the Glossary has been brought up to date.

The writer is greatly indebted to his colleagues, Dr. Charles P. Berkey for advice and assistance in editing and Professor A. W. Grabau for suggestions regarding the sedimentary rocks.

J. F. K.

APRIL, 1904.

NOTE TO THE FOURTH EDITION.

In the fourth edition the pages relating to the recasting of rock-analyses (155–158) have been somewhat amplified, and factors for turning molecular proportions into percentages are introduced (pp. 166–167). An appendix to the Glossary brings the rock-names up to 1908.

J. F. K.

APRIL, 1908.

NOTE TO THE FIFTH EDITION.

In the fifth edition, tables of the sedimentary and metamorphic rocks have been added, and additional matter regarding the recalculation of the chemical analyses of rocks has been introduced. A series of selected analyses of the igneous rocks has been further recast so as to show the relative volumes of the light and dark-colored minerals. The writer is greatly indebted to Professor A. F. Rogers of Stanford University, for suggestions and for aid in bringing the Glossary up to 1911.

J. F. K.

AUGUST, 1911.

ABBREVIATIONS.

A. A. A. S., or Proc. Amer. Assoc. Adv. Sci. — Proceedings of the American Association for the Advancement of Science.

Amer. Geol., or A. G. — American Geologist.

Amer. Jour. of Sci., or A. J. S. — American Journal of Science, sometimes called Silliman's Journal.

Bull. Geol. Soc. Amer. — Bulletin of the Geological Society of America.

Bull. Mus. Comp. Zoöl. — Bulletin of the Museum of Comparative Zoölogy, Harvard University, Cambridge, Mass.

Jahrb. d. k. k. g., Reichs. — Jahrbuch der kaiserlichen, königlichen Geologischen Reichsanstalt, Vienna, Austria.

Jour. of Geol. — Journal of Geology, published at the University of Chicago.

Neues Jahrb., or N. J. — Neues Jahrbuch für Mineralogie, Geologie und Palaeontologie, Stuttgart, Germany.

Quar. Jour. Geol. Soc., or Q. J. G. S. — Quarterly Journal of the Geological Society of London.

Tsch. Mitth. — Tschermak's Mineralogische und Petrographische Mittheilungen, Vienna, Austria.

U. S. Geol. Surv. — United States Geological Survey, Washington, The Publications are Bulletins, Monographs, Annual Reports. Folios and Professional Papers.

Zeits. d. d. g. Ges. — Zeitschrift der deutschen geologischen Gesellschaft, Berlin, Germany.

Zeits. f. Krys. — Zestschrift für Krystallographie, Munich, Germany.

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A HAND BOOK OF ROCKS.

For Use Without the Microscope.

CHAPTER I.

Introduction. Rock-forming Minerals. Principles of Classification.

A rock may be best defined as any mineral or aggregate of minerals that forms an essential part of the earth. The word mineral is used because this is our most general term for all inanimate nature, and while the lifeless remains of organisms often contribute in no small degree to rocks, no rock is made up of those which are still alive. In instances a single mineral forms a rock, but among minerals this is the exception. By far the greater number are in such small amount that they cannot properly be considered rocks. Rock-salt, ice, calcite, serpentine, cemented fragments of quartz, kaolin and a few others are in sufficient quantity, but the vast majority of rocks consist of two or more. The condition that a rock should form an essential part of the earth is introduced to bar out those minerals or aggregates, which, though important in themselves, are none the less insignificant as entering into the mass of the globe. Thus the sulphide ores, while locally often in considerable quantity, when broadly viewed are practically neglectable. Yet this is somewhat arbitrary and there are single minerals and aggregates that may properly give rise to differences of opinion. The following pages err, if at all, on the side of demanding that the amount should be large. A rock must also have an individual character, sufficient to establish its identity with satisfactory sharpness. The species cannot be marked off with the same definition as in plants, animals, or minerals, and there is here again reasonable opportunity for differences of opinion as to the limits which should be set, some admitting of finer distinctions and greater multi-

plicity of species than others; but, after all has been said, there should be a well-marked individuality to each rock species which any careful and qualified observer may readily recognize. Too great refinements and too minute subdivisions ought to be avoided. The determining conditions of species will be taken up at greater length, when the preliminaries of classification have been set forth, but it must be appreciated that the point of view is also a most important factor. Thus if one is studying the geology of a district with close accuracy, and is tracing out the history and development of its rocks with microscopic determinations and descriptions of minerals and structures which may be minute, finer distinctions will naturally be drawn than those that suggest themselves to one who is engaged in ordinary field work or in mining or engineering enterprises. It is for the latter class that these pages are prepared and throughout the descriptions and classification here given, the necessary limitations and the practical needs of such observers are always kept in mind. Textural and mineralogical distinctions are alone emphasized where easily visible on a specimen, although never made contradictory of principles of origin and classification which could be carried to greater length and subdivision.

Rocks embrace matter in a great variety of structures and conditions. While in general we picture them to ourselves as solid, yet under the terms of our definition, we have no logical right to bar out liquids or even gases. The physical condition may vary with ordinary temperatures. Thus we cannot reject ice as an extremely abundant and important rock, and yet its solid condition results from water with a moderate loss of heat, and at ordinary temperatures the same molecules may be in a liquid or gaseous state. All that we know of volcanoes indicates that liquid, molten magmas exist for long periods deep in the earth, yet they are none the less rocks because of their liquidity. In general, however, rocks are solid, and gases or liquids (except water) deserve no further attention. In texture rocks may be loose and incoherent as in sand, gravel, volcanic dust and the like, or they may be extremely dense, hard and solid, as in countless familiar examples. This solidity or massiveness has its limitations, for all observation and experience show that what are apparently solid

masses are really broken up by multitudes of cracks into pieces of varying size. All quarries and mines have these, and they may aid or annoy the operators according to the purposes of excavation. They will again be referred to at length. Unless too deep within the earth, rocks are also in all cases permeated with minute pores and spaces that admit of the penetration of water and other liquids, especially if under pressure. These are important factors in terrestrial circulations.

The Chemical Elements Important in Rocks.

The chemical elements really important in rocks are comparatively few, and are those which are most widespread in nature. The best estimate which has been made is that of F. W. Clarke, in Bulletin 616 of the U. S. Geological Survey, p. 34, 1916. Analyses of all the accessible terrestrial matter, including the air and the ocean, have been used. The average composition of the igneous rocks has first been determined; next that of the sedimentary types. Since the metamorphic rocks represent either igneous or sedimentary originals, they do not call for special treatment. The average composition of the ocean and that of the atmosphere have been computed. In the general composition of the rocky crust the igneous rocks are assigned 95 per cent.; shale 4 per cent.; sandstone 0.75 per cent.; limestone 0.25 per cent. In the final average the rocky crust is credited with 93 per cent.; and the waters with 7 per cent., both in round numbers since the atmosphere is but 0.03 per cent. of the total.

Oxygen.....50.02	Potassium.....2.28	Fluorine.....0.10
Silicon.....25.80	Hydrogen.....0.95	Barium.....0.08
Aluminum..... 7.30	Titanium.....0.43	Manganese....0.08
Iron..... 4.18	Chlorine.....0.20	Nitrogen.....0.03
Calcium..... 3.22	Carbon.....0.18	Strontium.....0.02
Magnesium.... 2.08	Phosphorus....0.11	All others.....0.47
Sodium..... 2.36	Sulphur.....0.11	Total...100.00

It is of interest to remark that of all the common metals, useful in the arts, only aluminum, iron and manganese appear in the table.

There is good ground for believing that toward the center of the earth the metallic elements become much more abundant, and that near the center some of the heaviest known are in excess, but these inferences, however well-based, concern materials far beyond

actual experience, and of no great moment in this connection. As regards rocks we have to deal with the outer portions of the globe, to which we are accustomed to refer as the crust. This term is not meant to indicate anything as to the condition of the interior, but merely the exterior as contrasted with the inner parts.

The chemical elements above cited are combined, except perhaps in volcanic glasses, in the definite compounds which form mineral species. These compounds change, more or less, in the course of time, under the action of various natural agents, chief of which are water, carbonic acid and oxygen, but at any particular stage, however complex the rock may be, it is made up of definite chemical compounds, though we may not be able to recognize them all. The most important compounds are not numerous and are practically limited to the following: silicates, oxides, carbonates, sulphates, chlorides, and of far inferior moment phosphates, sulphides, and one native element graphite.

As a broad conception in speaking of these compounds it is in many respects advantageous to have the igneous rocks primarily before our minds, because as stated above they are the sources of the others. In taking up the minerals the purpose here is to emphasize their chemical composition and relative importance, not to describe them as would be done in a text-book on mineralogy so as to enable a student to recognize them, for such preliminary knowledge is here assumed. Our purpose is to make prominent the chief chemical compounds entering into the earth, and to prepare the way for a true conception of the range and relations of its constituent rocks.

The Silicates.

The Silicates are grouped as follows: the feldspars and feldspathoids; the pyroxenes; the amphiboles; the micas; olivine. The last four groups are often collectively called the ferro-magnesian silicates. Zircon and titanite conclude the list of those important in igneous rocks. In addition there are a number of others that are especially characteristic of altered or metamorphosed rocks, viz: epidote, scapolite, garnet, tourmaline, topaz, andalusite, cyanite, fibrolite or sillimanite, and staurolite. Finally a few hydrated silicates complete the list.

THE FELDSPARS and their related minerals are all double silicates of alumina and an alkali or an alkaline earth or both. We speak of them as alkali-feldspar, potash-feldspar, soda-feldspar, lime-soda feldspar, etc., based on this fact. They are generally grouped as orthoclase, representing monoclinic feldspar with its two cleavages at right angles (hence the name), and as plagioclase or triclinic feldspar, with oblique cleavages, and one striated cleavage plane. Orthoclase and albite are salts of $H_4Si_3O_8$ in which one monad element potassium or sodium and one triad, aluminum, satisfy the acid radicle. Anorthite, on the other hand, is a salt of $2(H_4SiO_4)$, one dyad, calcium, and two triads, aluminum, making eight bonds of affinity in all being required to satisfy the acid radicles. Orthoclase is chiefly $K_2O,Al_2O_3,6SiO_2$, which expanded form may be condensed to $KAlSi_3O_8$. Na_2O replaces more or less of the K_2O, without affecting the crystal system. Sufficient amounts of soda are however capable of changing the system to triclinic and the feldspar is called anorthoclase. Microcline is also a triclinic variety of potash feldspar, with a cleavage angle slightly less than a right angle, but with peculiar and characteristic optical properties, which are chiefly of moment in microscopic work. The clear, unclouded orthoclase of the later volcanic rocks is often called sanidine. It does not differ essentially from the orthoclase of the older rocks, and the distinction based on geological age is obsolete, but as the terms are still used in the literature of the subject it is well to understand them.

The plagioclase feldspars embrace a practically unbroken series from pure soda-alumina silicate in albite, $Na_2O,Al_2O_3,6SiO_2$ or when condensed $NaAlSi_3O_8$, to pure lime-alumina silicate, anorthite, $CaO,Al_2O_3,2SiO_2$ or $CaAl_2Si_2O_8$. Various mixtures of these two molecules give the intermediate species, but the two on which special stress is ordinarily placed are oligoclase, with soda in excess and hence called soda-lime feldspar, and labradorite with lime in excess and hence called lime-soda feldspar. If we represent the orthoclase molecule, $KAlSi_3O_8$ by Or; the albite molecule, $NaAlSi_3O_8$ by Ab; and the anorthite, $CaAl_2Si_2O_8$ by An; all the intermediate feldspars can be algebraically expressed. Thus anorthoclase lies between Ab_2Or_1, and $Ab_{4.5}Or_1$; albite embraces those from Ab through Ab_8An_1; oligoclase, Ab_6An_1,

through Ab_2An_1 (the intermediate mixtures Ab_3An_2 through Ab_4An_3 are called andesine); labradorite includes Ab_1An_1 through Ab_1An_2; bytownite Ab_1An_3—Ab_1An_6; anorthite Ab_1An_8 to An. This conception of feldspars as isomorphous mixtures of molecules is a very valuable one and by determining specific gravity, optical properties and chemical composition, one or all, the different members can be identified. Practically, however, in the ordinary determination of rocks, aside from microscopic work, we are forced by the difficulty of distinguishing the intermediate varieties, into the general use of orthoclase and plagioclase, and rely on the presence or absence of the striations peculiar to the basal cleavage of the latter in distinguishing between the two, but of course experience and familiarity with the general characters and associations of minerals in rocks often enables one to determine very closely the minor varieties. We would naturally look for orthoclase, albite and oligoclase in acidic rocks or those high in silica, while in basic rocks we would expect those near the anorthite end.

All the feldspars have very similar crystal forms when these are developed, as they occasionally are in rocks. When they are small and irregularly bounded, cleavage faces should be sought out and examined with a pocket lense. It is interesting to note that only in igneous rocks do we obtain crystals uniformly developed on all sides, for only in a fused magma do they swim and grow without a fixed support.

The word feldspar is spelled by English writers "felspar," but among Americans the more correct form, based on the etymology, is employed, following the German original "Feldspath."

FELDSPATHOIDS. With the feldspars are placed two other important and closely related minerals, nephelite and leucite, to which may also be added one that is quite rare, melilite. *Nephelite* is an hexagonal, soda-alumina silicate, $4Na_2O,4Al_2O_3,9SiO_2$, in which some of the Na_2O is replaced by K_2O and CaO. It appears in a subordinate series of igneous rocks that are rich in soda. *Leucite* is an isometric potash silicate, $K_2O,Al_2O_3,4SiO_2$, with a little Na_2O replacing part of the K_2O. It is a salt of metasilicic acid, H_2SiO_3, like the pyroxenes and amphiboles, but because of the triad element, aluminum, it is necessary to have two of the acid radicles. Thus dividing the expanded formula given above, by 2 and con-

densing we have $KAlSi_2O_6$. It appears as an important rock-making mineral in the igneous rocks of ten or fifteen localities the world over, and is therefore of very limited distribution. *Melilite* is an extremely basic, lime-alumina silicate, $12CaO,2Al_2O_3,9SiO_2$, and appears in a few rare basalts.

Reference may also be made to sodalite, noselite and haüynite which are occasionally met, but which are chiefly of microscopic interest.

The feldspars, together with the feldspathoids nephelite and leucite, are the most important of the rock-making minerals in their relations to the classification of rocks.

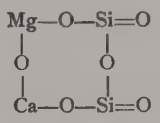
In order to have a standard series of analysis with which to compare those of rocks later given, the following table is inserted of theoretical feldspars and feldspathoids. The relative amounts of the several oxides will suggest the extent to which the molecules are present in any rock whose analysis is known:

	OR ORTHOCLASE $KAlSi_3O_8$	AB ALBITE $NaAlSi_3O_8$	AN ANORTHITE $CaAl_2Si_2O_8$	NEPHELITE $Na_8Al_8Si_9O_{34}$	LEUCITE $KAlSi_2O_6$	MELILITE $Ca_{12}Al_4Si_9O_{36}$
SiO_2	64.7	68.6	43.1	45.0	55.0	38.1
Al_2O_3	18.4	19.6	36.8	34.3	23.5	14.5
K_2O	16.9				21.5	
Na_2O		11.8		20.7		
CaO			20.1			47.4
Sp. Gr.	2.57	2.62	2.75	2.58	2.48	2.93

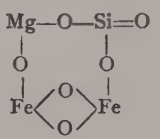
Recalling what has been said about the replacement of the alkalies by one another, and that we never meet any of these minerals chemically pure, according to the formulas above given, and making suitable allowance for this replacement, we may still appreciate that orthoclase and albite, being high in silica, favor acidic rocks, and the others being low in silica, basic ones; that nepheline implies a magma rich in alumina and soda, leucite one rich in potash, and melilite one low in silica and alumina, but high in lime.

THE PYROXENES and the AMPHIBOLES are best described together. Each embraces a series of compounds of the same chemical composition, differing only in physical and optical properties. As the table shows, they vary from magnesia silicate through a series of lime and lime-alumina silicates, with an iron silicate generally present. They are all primarily salts of metasilicic acid, H_2SiO_3. The monad and dyad bases, sodium, calcium, magnesium and

ferrous iron make simple and easily understood compounds, such as Na_2O, SiO_2; CaO, SiO_2; MgO, SiO_2; and FeO, SiO_2. On analysis however the triad bases, ferric iron and aluminum are quite invariably found in augite and hornblende. This was not easy to understand until the following replacement was suggested. If we write the formula of the diopside molecule graphically it will appear as follows:



Now in the lower line the calcium and silicon have together six bonds of affinity. So have two ferric irons, or two aluminums. If, therefore, we replace the calcium and silicon with the two irons we will have,



This is a common molecule in augite. Condensed it will be $MgFe_2SiO_6$. We also have $MgAl_2SiO_6$. The explanation will serve to make clear the condensed formulas of the several molecules as given in the table below, for otherwise the molecules with the triad elements and with only one silicon often prove very puzzling. The graphic formula for diopside will also show how two bases may enter a single molecule. All the pyroxenes have a prismatic cleavage of nearly 90° (87° 10′ or thereabouts), while the amphiboles cleave along a prism of nearly 120° (124° 11′).

COMPOSITION.	PYROXENE.	AMPHIBOLE.	SYSTEM.
$MgOSiO_2$, $FeOSiO_2$	Enstatite, Bronzite, Hypersthene	Anthophyllite	Orthorhombic
$CaMgSi_2O_6$	Diopside	Tremolite	Monoclinic
$CaMgSi_2O_6$, $CaFeSi_2O_6$	Malacolite, (Diallage)	Actinolite	Monoclinic
$CaMgSi_2O_6$, $CaFeSi_2O_6$, $MgAl_2SiO_6$, $MgFe_2SiO_6$, $FeAl_2SiO_6$	Augite	Hornblende	Monoclinic
$NaFeSi_2O_6$	Acmite, Ægirine	Arfvedsonite	Monoclinic

Under the orthorhombic pyroxenes enstatite has least of the molecule FeO,SiO_2, *i. e.*, FeO less than 5 per cent.; bronzite has FeO more than 5 and less than 14 per cent.; while hypersthene has still higher percentages of FeO. The increase brings about a darker color and changed optical properties. The orthorhombic pyroxenes are much less frequent than the monoclinic, but are of wide distribution, especially hypersthene. The orthorhombic amphiboles are of minor importance and are but seldom met.

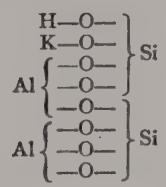
The light-colored monoclinic pyroxenes are almost pure lime-magnesia silicates, and are called diopside. They are chiefly found in crystalline limestones. As iron increases, they pass into malacolite, which may also contain small amounts of the aluminous molecules. Neither of these pyroxenes is of special abundance as a rock-maker. When pinacoidal cleavages around the vertical axis appear in addition to the prismatic ones, in pyroxenes of the general composition of malacolite they are called diallage and are important in some igneous rocks. But the chief rock-making pyroxenes are the dark aluminous, ferruginous ones, which are called augite, and these are among the most important of all minerals in this connection. The igneous rocks rich in soda, in which nepheline is common, are the ones that contain acmite and ægirite, the soda-pyroxenes.

The monoclinic amphiboles are closely parallel in their occurrence and relations to the pyroxenes. Tremolite is met in crystalline limestones. Actinolite may form schistose rocks by itself, but much the most important variety is hornblende, the aluminous variety corresponding to augite. The soda amphibole, arfvedsonite, is rare.

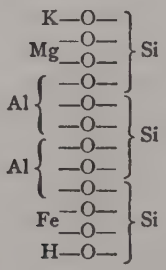
The pyroxenes and amphiboles are often collectively referred to as the bisilicates, the oxygen of the base being to the oxygen of the silicon, as shown in the first two formulas, in the ratio of 1 : 2. It is also interesting to note that many blast furnace slags are calculated on the basis of the formulas for pyroxene.

The Micas. All the micas are salts of orthosilicic acid, H_4SiO_4. This acid radicle will be satisfied by one monad base and one triad together, such as potassium and aluminum, but as dyad bases also occur with both these it is necessary to assume multiples of the

orthosilicic acid. Thus muscovite, the simplest of the common micas, has a graphic formula like this



For biotite which is more complex we need three molecules of the acid as follows:



Ferric iron may take the place of the aluminum, and various other variations may be made of this general formula. When condensed, the formula for muscovite will be $HKAl_2Si_2O_8$, and the variety of biotite given above will be $HKMgFeAl_2Si_3O_{12}$.

Biotite is the dark mica and is much the commonest of the group. It is very widespread, and is easily recognized by its cleavage — even small crystals can be picked apart into leaves with the point of a knife. Biotite is often called magnesia-mica. It enters into the classification of igneous rocks in an important way. Phlogopite is a lighter-colored but closely related variety, which favors crystalline limestones. Muscovite, from its richness in potash, is often called potash-mica. It is widespread in granites and schists. In composition it closely resembles orthoclase.

Olivine, the unisilicate of magnesium and iron, $2(Mg, Fe)O, SiO_2$, completes the list of silicates which are of the first order of importance in igneous rocks. The above name is usually employed in preference to chrysolite. Olivine is practically limited to basic igneous rocks. Like the micas it is an orthosilicate.

Zircon and titanite are interesting microscopic accessories, but as rock-making minerals they are seldom visible to the naked eye.

Along the contacts of intrusions of heated igneous rocks, and in regions where the original sediments have undergone strong dynamic disturbances, with oftentimes attendant circulations of waters more or less heated, a series of characteristic silicates is in each case developed. Garnet, tourmaline, topaz, andalusite, scapolite and biotite are especially characteristic of the former; garnet, cyanite, sillimanite, staurolite, biotite, and muscovite of the latter. Details of the development and associations of each of these groups are subsequently given under the metamorphic rocks. Epidote results when feldspars and the ferro-magnesian silicates undergo decay and alteration in proximity, so that the solutions afforded may react on one another.

The hydrated silicates of chief importance include a magnesian series, embracing talc and serpentine, which result from the ferro-magnesian minerals; a ferruginous aluminous series, with much iron oxide, usually collectively called "chlorite," and derived from the iron-alumina silicates; and finally kaolin, the hydrated silicate of alumina that is chiefly yielded by feldspar. Zeolitic minerals are also often met, but rather as vein fillings and in amygdaloidal cavities than as important rock makers.

The oxides include quartz and its related minerals chalcedony and opal, and the oxides of iron — magnetite and hematite and the hydrated oxide, limonite. With these should be mentioned chromite and ilmenite (menaccanite), which are of minor importance. Quartz is found in all rocks high in silica. Magnetite and hematite are at times almost abundant enough to constitute rocks themselves. They favor igneous and metamorphic varieties when present in a subordinate capacity. Magnetite is the most widespread of all the rock-making minerals. Limonite is an alteration product. Chromite is practically limited to the basic igneous rocks and their serpentinous derivatives. Ilmenite is a common accessory in many igneous rocks.

The carbonates are calcite, dolomite and siderite, all three being really members of an unbroken series from pure carbonate of calcium, through admixtures of magnesium carbonate to pure magnesite on the one hand or with increasing carbonate of iron to pure siderite on the other. The sulphates of moment are anhydrite and gypsum, the latter the hydrous, the former the anhydrous salt of

lime. The one chloride is the sodium chloride, rock salt or halite, and the one phosphate is apatite, which is a phosphate and chloride of lime. The two sulphides of iron, pyrite and pyrrhotite are the only ones sufficiently widespread to deserve mention, and graphite is the chief representative of the elementary substances, although native sulphur might perhaps with propriety be also mentioned.

We speak of minerals as essential and accessory, meaning by the former term those that constitute a large part of the rock, and that must be mentioned in the definition; by the latter those that are present in small amounts or that are more or less fortuitous. Primary minerals are those that date back to the origin of the rock, as for instance the ones that crystallize out from a molten magma as it solidifies; secondary minerals are formed by the alteration of the primary. Feldspars, pyroxene and hornblende are good illustrations of the former; hydrated silicates of the latter.

The Principles Underlying the Classification of Rocks.

Rocks must of necessity be classified in order to place them in their natural relations so far as possible and to allow of their systematic study. At the same time they are so diverse in their nature and origin that the subject is not an easy one. They must however be grouped on the basis of their structures and textures; or of their mineralogical composition; or of their chemical composition; or of their geological age; or of their method of genesis. One or several of these principles enter into all schemes. On the basis of the first, rocks have been classified as massive and stratified; as crystalline and fragmental or clastic, each with subdivisions on one or more of the other principles. On the basis of the second we have had those with only one mineral (simple rocks) and those with several (complex rocks). The chemical composition as shown by a total analysis (bausch-analysis), without regard to special mineral components, is of almost universal application in a subordinate capacity. It must be regarded in the group of igneous rocks and in those that are deposited from solution, chiefly highly calcareous or highly siliceous rocks. The principle of geological age was formerly much valued in connection with the igneous rocks, but it

is a thoroughly exploded one. The principle of origin or genesis is the most philosophical of all as a fundamental basis, but while in the greater number of cases it may be readily applied there are some puzzling members whose entire geological history is not well understood. Very early in the development of the subject it was appreciated that there were two great, sharply contrasted groups, according as the rocks had consolidated and crystallized from a molten condition or had been deposited in water either as mechanical fragments or as chemical precipitates. Widened observation, especially in arid and sandy regions, has added to these a less important group of those whose particles have been heaped together by the wind. They are called the eolian rocks and will be taken up together with the aqueous, with which they have many points in common. Two grand divisions have therefore been established, the igneous, on the one hand, and the aqueous and eolian on the other.

Even a limited field experience soon convinces the observer that many rocks are encountered which cannot be readily placed with either of the two great classes whose origin is comparatively simple. Rocks for instance are met having the minerals common to the igneous but with structures that resemble those of sediments in water.

Great geological disturbances, especially if of the nature of a shearing stress, may so crush the minerals of any igneous rock and stretch them out in bands and layers as to closely imitate a recrystallized sediment. The baking action of igneous intrusions on fine sediments, such as clays and muds, makes it difficult for an observer, without the aid of thin sections and a microscope, to say where the former sediment ends and the chilled magma begins. Sediments buried at great depths and subjected to heat and hot water become recrystallized with their chemical elements in new combinations. These excessively altered rocks have been often grouped into a separate, so-called "metamorphic" division, which was a sort of "omnibus" of unsolved geological problems. This metamorphic group is useful, and the term is a common one in the science, but wherever possible it is well to appreciate the true affinities of its members which though altered are still referable to their originals.

In the following pages these three divisions will be adopted, but the metamorphic group will be reduced to a minimum by remarking, in connection with descriptions of the unaltered rocks, the changes that igneous and aqueous undergo.

We take up, therefore, in this order :

A. The Igneous Rocks.

B. The Aqueous and Eolian Rocks.

C. The Metamorphic Rocks.

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FIG. 1. Dike of andesite 15 ft. thick and 50 ft. high, cutting sandstones. Ortiz arroyo, near Los Cerrillos, N. M. D. W. Johnson, School of Mines Quarterly, July, 1903, 461.

FIG. 2. Surface flow. Black Rock Mesa, Leucite Hills, Wyo. Kemp and Knight, Bulletin Geol. Soc. Amer., XIV., 323, 1903.

FIG. 3. Volcanic Neck. The Boar's Tusk, Leucite Hills, Wyo. Kemp and Knight, Bull. Geol. Soc. Amer., XIV., 328, 1903.

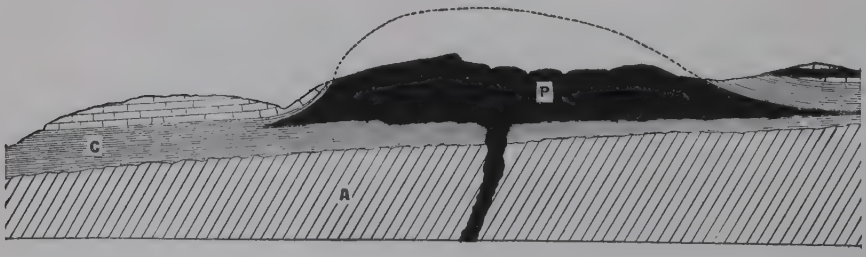


FIG. 4. Laccolith. Cross-section of the Ragged Top laccolith of phonolite, Black Hills, S. D. J. D. Irving, Annals N. Y. Acad. Sci., XII., Plate VI., 1899.

CHAPTER II.

General Introduction to the Igneous Rocks. Classification.

The Igneous rocks are first treated because they have been the originals, according to our best light, from which all the others have been directly or indirectly derived, for either from the fragments, as afforded by their decay, or from the mineral solutions, yielded by their alteration, possibly in the primitive history of the globe, all the others have been produced.

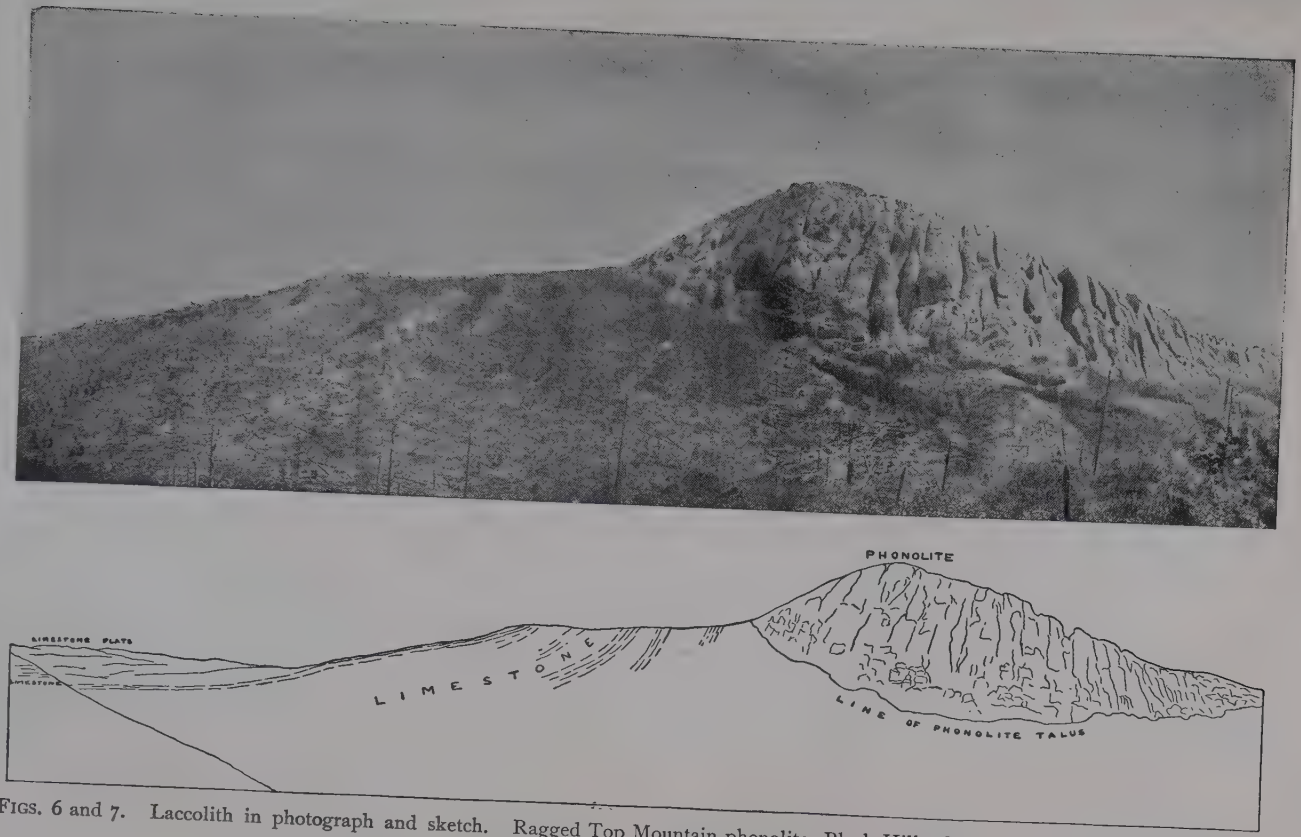
The igneous rocks occur in dikes, sheets, laccoliths, bosses and vast irregular bodies, for which we have no single term. Dikes (spelled also dykes) have penetrated fissures in other rocks, and have solidified in them. They therefore constitute elongated and relatively narrow bodies, of all sizes, from a fraction of an inch in thickness and a few feet in length, to others a thousand or more feet across and miles in length. Sheets are bodies of relatively great lateral or horizontal extent, compared with their thickness. They are either surface flows, which may be afterwards buried or else are intruded between other strata. In the last case, if lenticular in shape, they are often called laccoliths. Roughly cylindrical masses, such as might chill in the conduit of a volcano, are called necks. Irregular, projecting, rounded bodies are called bosses. The enormous masses of crystalline rocks like granite that often cover hundreds of square miles, and that frequently appear to have fused their way upward by melting overlying rocks into their substance, are called batholiths. They have in most if not all instances, only been uncovered by erosion, for the name means a rock belonging to the depths of the earth. It will be later brought out that the character of the occurrence, whether as dike, surface flow, intruded sheet, or batholith, has an important influence on the texture.

Igneous rocks are characteristically massive, as contrasted with the stratified structure of the sedimentary, and the term massive is sometimes employed as a synonym of igneous. Other synonymous terms are eruptive and anogene, both meaning that the rocks

FIG. 5. Two intruded sheets of andesite-porphyry, the larger one several hundred feet thick, the smaller 130 ft., near New Madrid, N. M. D. W. Johnson, School of Mines Quarterly, April, 1903, 339.

have come up from below. Many years ago the distinction was made between those that have crystallized deep within the earth, the plutonic, and those that have been poured out on the surface, the volcanic. The words intrusive and effusive or extrusive have been employed in much the same way. Between surface flows and deep-seated masses (batholiths) and their characteristic textures, every gradation is to be expected and is met, and an intermediate group has even been established by some writers for rocks that have cooled as intruded sheets and dikes. This three-fold distinction is not carried out here, the two extremes being believed to illustrate the varieties satisfactorily when accompanied by auxiliary remarks on the intermediate types.

We are tending more and more to employ the word structure for the larger features of a rock, as for instance a massive structure as against a stratified, while the smaller features are described as textures, as for instance a glassy texture, a porphyritic or a granitoid, terms that refer to characters which may be seen even on a small fragment. Glassy texture, as the name implies, is that of glass or slag and has no definite minerals. It results when a molten magma is so quickly chilled that the minerals have no opportunity to form. Porphyritic implies larger crystals, well formed or corroded and rounded, embedded in a more finely



FIGS. 6 and 7. Laccolith in photograph and sketch. Ragged Top Mountain phonolite, Black Hills, S. D. J. D. Irving, Annals N. Y. Acad. Sci., XIV., Pl. XII., 1899.

crystalline, or even in a "glassy groundmass." There may be several sizes and kinds of these crystals, and because of their prominence in the rock they are called phenocrysts, *i. e.*, apparent crystals, but phanerocryst is better etymologically. If a magma crystallizes as a mass of very fine or microscopic crystals without phenocrysts, its texture is described as felsitic. A granitoid or granular texture has the component crystals all of about the same size, and very seldom possessing their own crystal boundaries. Strictly speaking, there is no groundmass in granitoid rocks. Sometimes from a local abundance of mineralizers (as later explained), granitoid rocks have small cavities into which the component minerals project with well-bounded crystals. Such are called *miarolitic.*

Textures in igneous rock are due to several factors that have influenced the development of the magma during its consolidation. The most important are chemical composition, temperature, rate of cooling, pressure and the original presence of dissolved vapors called mineralizers. The fusibility varies with the *chemical composition.* The most acid or siliceous magmas, *i. e.*, those with 65–75 per cent. SiO_2 are least fusible. When molten they are viscid and ropy. The fusibility increases with the decrease of silica down to the basic rocks with 40 to 50 per cent. SiO_2. The ultra-basic rocks which graduate into practically pure bases, as in some rare, igneous iron ores, are less fusible. This statement that acid rocks are least fusible often puzzles a student who is familiar with blast furnace practice and the composition of slags, in which the most siliceous are regarded as most fusible, but slags themselves, as a comparison of analyses will readily show, are to be paralleled with basic rocks. The importance of the fusibility as regards textures lies in the fact that the highly siliceous quickly chill, become ropy and freeze. They therefore especially yield glasses. The easily fusible remain fluid at lower temperatures, crystallize out as minerals to a greater degree and seldom yield glasses. They flow farther from the vent and tend to develop the porphyritic or even a variety of granular texture. The influence of *temperature* has been partly outlined in speaking of composition, but it will readily appear that in its progress to the surface a basic magma might stand for a considerable period at a temperature of fluidity, whereas

an acid magma in the same situation would consolidate. The *rate of cooling* is important. Cooling magmas tend to break up into minerals. As a general thing it requires a very quick chill to prevent their formation. Hence it is that even volcanic glasses which appear to be perfect glass to the eye are shown to be full of dusty, microscopic minerals under the microscope. Volcanic glasses are chiefly found on the outer portions of flows or dikes, but instances are known where sheets of them are very thick, as at Obsidian Cliff in the Yellowstone Park. The common experience with lavas is that certain crystals develop to notable size, it may be an inch or more in diameter, while the magma stands beneath the surface, in circumstances favorable to their formation. These are then caught up in the moving stream and brought to the surface or near it where the final consolidation takes place and fixes them in the so-called groundmass. A quick chill makes a fine-grained groundmass when not a glassy one, and slow cooling yields one more coarsely crystalline, but in the final cooling or consolidation at or near the surface, crystals are seldom if ever developed of a size commensurable with those formed in the depths. By this process of partial crystallization below and final consolidation on the surface, the porphyritic texture is almost always developed, but in strict accuracy it should be stated that cases are known where phenocrysts appear to have formed in lavas after coming to rest. Magmas also flow to the surface with no phenocrysts (or "intratelluric" crystallizations) and then consolidate not as glass, but as finely crystalline aggregates, practically all groundmass. The resulting texture is called felsitic.

Pressure, such as is developed upon a magma deep within the earth or during its passage to the surface is thought to exert an influence upon the formation of many phenocrysts and to be necessary for their development. *Dissolved vapors*, such as steam, hydrofluoric and boracic acids, are also important factors. Acidic magmas are more generally provided with them than basic, and where locally abundant they lead to variations both in the mineral composition and texture at different places in the consolidated rock. They may prevent the development of glass, and cause a sheet such as Obsidian Cliff, in the Yellowstone Park, to present alternations of glassy and stony layers, the latter being formed of microscopic crystals.

A word should be added about the chemical composition of rocks and about the interpretation of analyses before the rocks themselves are taken up. The analyses are reported in percentages of oxides, for the most part, and these are arranged in the following series, SiO_2, Al_2O_3, Fe_2O_3, FeO, CaO, MgO, Na_2O, K_2O, H_2O. In order to have anhydrous materials, it is customary to ignite and determine loss on ignition. This loss includes both H_2O and CO_2 and where large throws uncertainty over the relations of the elements left behind, because of the evident advance of decay. Small percentages of other oxides are quite invariably present and in refined work are determined. These are TiO_2, MnO, NiO, BaO, SrO, S, Cl, P_2O_5, Li_2O, and even rarer ones. They are however always in very small quantity. We often recast an analysis, by dividing, as in the determination of a mineralogical formula, each percentage by the molecular weight. We thus get numerical molecular ratios which indicate the relative numbers of individual molecules and enable us to draw conclusions as to the way in which they are combined with one another in the component minerals of the rock. If we know the chemical formulas of the minerals we can sometimes calculate the percentage of each in the rock. In Chapter XIII. this subject is further treated with an illustrative example. The calculations cannot however be made when two or more bases appear together in two or more minerals. Variations in chemical composition entail variations in resulting minerals, but it is also true that the same magma, if consolidating under different physical conditions of heat, pressure, etc., at different times may yield somewhat different minerals, for instance, hornblende instead of augite, or vice versa. A study of analyses soon makes one more or less familiar with the minerals that would necessarily result. The more important points are the amounts of silica, of the alkalies and alkaline earths, of iron oxides and of alumina. For instance, as a rule, only magmas high in SiO_2 yield quartz, for otherwise it would combine with the bases. Much K_2O is necessary for an orthoclase or leucite rock, but much Na_2O for one with nepheline. MgO in relatively large amount is required to yield olivine or an orthorhombic pyroxene, and when feldspars drop away and rocks become very basic we expect high CaO, MgO, FeO, Fe_2O_3, and low SiO_2. In rocks tested for pur-

poses of building, the percentage of sulphur is important and very little should be present. It occurs in some form of pyrites, which by its decay generates sulphuric acid and destroys the stone or stains it with limonite. It should never reach 1 per cent.

Using the molecular ratios as the basis of plotting, extremely interesting and significant diagrams have been devised, first for individual cases by W. C. Brögger * and later of groups by W. H. Hobbs,† so that the latter's figures are like composite photographs of the chemical composition of the several groups of igneous rocks. Diagrams of this sort are subsequently given which will epitomize for the student the chemical characteristics of each of the groups. Various other devices have been suggested but the ingenious plan of Brögger is the best.

The specific gravity or density of a rock is an important feature in its practical bearings. While it may in ice be less than 1, and in coals and certain carbonaceous deposits may drop as low as 1.25, and in very porous sandstones reach 2.25, yet in the common rocks it is seldom below 2.50, and ranges from this to over 3.00. Granites are usually about 2.65, but basic rocks, rich in iron, attain to the higher limits, even above 3.0. Determinations are important in those rocks used for building purposes, and are expressed in pounds per cubic foot.

Of recent years we have come to regard molten magmas as essentially solutions of some compounds in others, and to appreciate that solutions do not cease to be such, even when the temperature is very high. It results from this that the crystallization of the minerals of an igneous rock takes place from the magma as this in its cooling successively reaches a point of saturation for the salt in question. The least soluble separate the earliest of all, and then the others in order; but as the pressure under which they rest is also a factor, and this is subject to variation, as indeed is the temperature during movement to the surface, one mineral's period of formation may overlap another's more or less. The order of formation will be determined by the laws of thermodynamics and necessarily the mineral that develops the most heat in crystallizing will be the first to crystallize. As a general rule,

* "Das Ganggefolge des Laurdalits," Kristiania, 1898, 255.

† "Suggestions Regarding the Classification of the Igneous Rocks," Journal of Geology, VIII., 1, 1900.

the relations of the minerals in rocks show that the earliest to form are apatite; the metallic oxides (magnetite, ilmenite, hematite); the sulphides (pyrite, pyrrhotite); zircon and titanite. These are often called the group of the ores. Next come the ferromagnesian silicates, olivine, biotite, the pyroxenes and hornblende. Next follow the feldspars and feldspathoids, nepheline and leucite, but their periods often begin well back in that of the ferromagnesian group. Last of all, if any excess of SiO_2 remains, it yields quartz. In the variation of the conditions of pressure and temperature just referred to, it may and does often happen that crystals are again redissolved in the magma, or are resorbed, as it is called; and it may also happen that after one series of minerals, usually of large size and of intratelluric origin, has formed, the series is again repeated on a small scale as far back as the ferromagnesian silicates. Minerals of a so-called second generation thus result, but they are always much smaller than the phenocrysts, and are characteristic of the groundmass.

It follows from what has been stated that the residual magma is increasingly siliceous up to the final consolidation, for the earliest crystallizations are largely pure oxides. It is also a striking fact that the least fusible minerals, the feldspars and quartz, are the last to crystallize and therefore we must introduce the conception of solution in order to explain the process; otherwise the minerals would inevitably form in the reverse order of their fusibilities, the most infusible leading off. The accompanying table of fusing points will be of interest in this connection. It must be borne in mind that no mineral can crystallize while the magma has a temperature above its fusing point for the conditions of pressure prevailing at the time.

TABLE OF THE FUSING-POINTS OF THE COMMON ROCK-MAKING MINERALS.

Ægirite	925° C.	Microcline	1155° C.
Hornblende	1025 to 1085°	Orthoclase	1175
Nephelite	1080 to 1095	Magnetite	1185
Augite	1085 to 1095	Hypersthene	1185
Albite	1110	Muscovite	1230
Oligoclase	1120	Leucite	1300
Labradorite	1125	Olivine	1350
Biotite	1130	Bronzite	1400
Sanidine	1130	Quartz fuses still higher.	
Anorthite	1132		

TABLE OF THE FUSING-POINTS OF SOME OF THE COMMON IGNEOUS ROCKS.

Granite	1240° C.	Basalt	1060° C.
Monzonite	1190	Limburgite	1050
Phonolite	1090	Lava (Etna)	1010
Lava (Vesuvius)	1080		

These values are taken from an abstract of a paper by C. Doelter, reviewed in the *Neues Jahrbuch*, 1903, Volume II., page 60. From them, it is evident that while olivine, for example, melts, at 1350°, limburgite, a rock containing large proportions of it, melts at 1050°. Magnetite, the earliest to crystallize of all the minerals mentioned, fuses of itself more than a hundred degrees above many of the rocks containing it.

In the matter of the study and determination of a rock species, especially of an igneous rock, it is desirable to procure materials as fresh and unaltered as possible. If feldspars have all changed to kaolin and clay, and if ferromagnesian silicates are merely chlorite or serpentine, and if secondary quartz, calcite and the like have formed, it is very difficult if not impossible to draw correct or even well-grounded inferences. Rocks near ore bodies are very often of this character.

Bearing in mind these differences of texture and the causes of them, it is possible to group igneous rocks in such arrangement that they can be intelligently studied, and identified with a reasonably close approximation to the truth. It should be appreciated, however, that with finely crystalline rocks, whose components are too small for the unassisted eye, the microscope is the only resource, and with this as an aid much greater subdivision can be attained. The object here in view is to limit the discussion purely to the study without the microscope.

The scheme of classification of the igneous rocks has three principles underlying it, viz: texture, mineralogical composition and chemical composition. The textures are five: glassy, felsitic, porphyritic, granitoid and fragmental, and the table is arranged from top to bottom so that they come in this order. The arrangement is adopted because it brings the glassy which are the simplest of all rocks at the outset, where they can be best taken up by the beginner. From top to bottom after the glassy rocks, the surface flows with their peculiar species come next, and then we pass through those with increasing proportions of phenocrysts, to the thoroughly granitoid. The word porphyry as a suffix has been

ACIDIC ← Excess of Light-colored Minerals. Excess of Dark-colored Minerals → BASIC.

Crusts, Surface Flows.	Glassy.	Acid Glasses, Obsidian, Perlite, Pumice, Pitchstone.			Andesite-Obsidian.				Basic Glasses, Scorias, Tachylyte, Basalt-Obsidian.				
		Chief Feldspar Orthoclase.			Chief Feldspar Plagioclase.				Nephelite, Leucite.		No Feldspar.		Ultra-basic Rocks
		Biotite (or) (and) Hornblende (or) (and) Augite.			Biotite (or) (and) Hornblende.		Pyroxenes.		Pyroxenes.		Augite (or) (and) Hornblende (or) (and) Biotite.		
		+ Quartz.	— Quartz.	Nephelite or Leucite.	+ Quartz.	— Quartz.	— Olivine.	+ Olivine.	— Olivine.	+ Olivine.	— Olivine.	+ Olivine.	
Surface Flows	Cellular, Glassy or Felsitic. Phenocrysts Few	Rhyolite (Felsite)	Trachyte (Felsite)	Phonolite (rare), Leucite Rocks (very rare)	Dacite (Felsite)	Andesite (Felsite)	Augite-Andesite	B A Basalt	S A L T G		R O Augitite	U P Limburgite	Basic Segregations in Normal Magmas.
Dikes, Intrusive Sheets, Laccoliths	Porphyritic. Phenocrysts Prominent	Rhyolite-porphyry (Quartz-porphyry)	Trachyte-porphyry	Phonolite-porphyry	Dacite-porphyry	Andesite-porphyry	Augite-Andesite-porphyry	Basalt-porphyry	A series of rare basaltic rocks with Nephelite (or) (and) Leucite, seldom Melilite or Analcite. Not readily distinguished from basalt without the microscope. Extremely rare in America.		Augitite-porphyry	Limburgite porphyry	
	Porphyritic. Phenocrysts Predominate	Granite-porphyry	Syenite-porphyry	Nephelite-Syenite-porphyry	Quartz-Diorite-porphyry	Diorite-porphyry	Gabbro-porphyry	Olivine-Gabbro-porphyry			Pyroxenite-porphyry	Peridotite-porphyry	Meteorites.
Laccoliths, Batholiths	Granitoid	Granite	Syenite	Nephelite, Syenite	Quartz, Diorite	Diorite	G Gabbro	A B Olivine-Gabbro	B R O G		R O Pyroxenite	U P Peridotite	Water. Ice.
Beds, Strata	Fragmental	Rhyolite Tuffs and Breccias	Trachyte Tuffs and Breccias	Phonolite Tuffs and Breccias	Dacite Tuffs and Breccias	Andesite Tuffs and Breccias	Andesite Tuffs and Breccias	Basaltic Tuffs and Breccias					
	SiO_2	80–65 %	65–55 %	60–50 %	70–60 %	65–50 %	65–50 %	55–45 %	50–40 %		55–30 %		30–0 %.

adopted for the intermediate members, which roughly correspond with the intrusive rocks. Finally the granitoid batholiths complete the succession. It must be appreciated however that the methods of field occurrence do not follow these textural differences in other than a general way. Thus thick surface flows will have dense porphyritic textures at their centers, and dikes are known with glassy borders. Thick, intrusive sheets and laccoliths are practically granitoid, like the batholiths and the batholiths themselves sometimes become roughly porphyritic from the exceptional development of the feldspars. But nevertheless an important general rule is emphasized by the arrangement, and the truth that texture is largely a function of depth and pressure, is brought out. Not all the rocks described in the text appear in the table, since some, such as diabase, on which much stress is laid, are left out. All these together with synonyms and relatives will be subsequently emphasized, so far as is appropriate for an elementary book.

The rocks are arranged from left to right on a mineralogical principle, and chiefly on the basis of the predominant feldspar present, as is the usual custom. This also makes possible a general succession from those most acidic on the left to those most basic on the right, but while this is true for the extremes it is not strictly so for intermediate points because dacites and quartz-diorites are far higher in silica than are phonolites and nephelite-syenites, and even than trachytes and syenites. The general range of silica is indicated on the lowest line. At the same time the importance of the bases is not to be overlooked and subsequent tables of analyses are given so as to show the ranges.

The general and larger truths of igneous rocks are fairly well brought out in condensed tables of this character, even though exceptional cases are known which would require its modification. But no attempt has been made to confuse the larger truths by mention of the rarer occurrences, for, as before stated, only ordinary examination is assumed in connection with this text. When rare and exceptional varieties are met they should be placed in the hands of a worker with a microscope. It should also be appreciated in connection with the table that groups of rocks shade into one another by imperceptible gradations and that they are not marked off with the sharpness of ruled spaces.

CHAPTER III.

The Igneous Rocks, Continued. The Glasses. The Rocks Whose Chief Feldspar is Orthoclase. The Phonolites and Nephelite-Syenites.

The Glasses.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	Loss.	Sp. Gr.
1.	79.49	11.60	0.33	0.49	1.64	0.09	1.52	4.04	0.68	
2.	76.20	13.17	0.34	0.73	0.42	0.19	4.46	4.31	0.33	2.352
3.	75.52	14.11	1.74	0.08	0.78	0.10	3.63	3.92	0.39	2.342
4.	74.70	13.72	1 01	0.62	0.78	0.14	4.02	3.90	0.62	2.345
5.	74.05	13.85	tr.	...	0.90	0.07	4.31	4.60	2.20	
6.	74.05	12.97	2.73	...	0.12	0.28	5.11	3.88	0.22	2.37
7.	74.01	12.95	...	1.42	0.99	0.48	4.65	5.34	0.29	2.391
8.	72.87	12.05	1.75	...	1.30	1.10	tr.	6.13	3.00	
9.	71.6	12.0	1.0	...	1.1	0.2	4.3	2.5	7.4	
10.	71.56	13.10	0.66	0.28	0.74	0.14	4.06	3.77	5.52	
11.	65.13	15.73	2.24	1.86	3.62	1.42	3.96	2.93	2.43	
12.	60.5	19.1	4.2	0.3	0.6	0.2	3.5	10.6	...	2.48
13.	54.28	14.83	14.73	...	7.02	3.65	1.27	4.22	...	2.704
14.	50.82	9.14	7.33	7.03	11.63	7.22	1.02	3.06	1.74	2.66
15.	45.73	20.15	12.46	...	8.67	3.59	4.11	5.74	0.12	

1. Pumice, Cinder Cone, Calif., J. S. Diller, Bull. 79, U. S. G. S., p. 29. 2. Black Obsidian, Tewan Mtns., N. M., J. P. Iddings, 7th Ann. Rep. U. S. G. S., 219. 3. Red Obsidian, Yellowstone Park, J. P. Iddings, 7th Ann. Rep. U. S. G. S., 219, also FeS_2 0.11. 4. Black Obsidian, Yellowstone Park, J. P. Iddings, 7th Ann. Rep. U. S. G. S., 219, also FeS_2 0.40. 5. Scoriaceous Obsidian, Mono Lake, Cal., I. C. Russell, 8th Ann. Rep. U. S. G. S., 380. 6 Obsidian, Lipari Is., Abich. Vulk. Ersch., 62. 7. Obsidian from Andesite, Clear Lake, Cal., G. F. Becker, Mon. XIII., U. S. G. S., 104. 8. Perlite, Hungary, Kalkowsky, Elemente der Lith., p. 75. 9. Pitchstone, Meissen, Lemberg, Z. d. d. g. G., XXIX., 508. 10. Pitchstone, Silver Cliff, Colo., W. Cross, Phil. Soc. Wash., XI., 420. 11. Andesitic perlite, Eureka, Nev. Hague, Mono. XX., U. S. G. S., 264. 12. Phonolite obsidian, Teneriffe, Abich. Vulk. Ersch., 62. 13. Hyalomelane, Ostheim, Germany, Lemberg Z. d. d. g. G., XXXV., 570. 14. Pele's Hair, Hawaii, Cohen, N. J., 1880, II., 41. 15. Tachylyte, Gethurms, Germany, Lemberg, See No. 13.

Comments on the Analyses.—An examination of the table of analyses indicates that the magmas are high in SiO_2, and relatively low in all other bases except the alkalies. The high Na_2O of Number 12 is worthy of remark, because this is the rule with a nephelite rock. The percentages under the column headed loss, which

practically indicate the H_2O present are characteristic for different varieties. They are low in the case of obsidians, Nos. 2, 3, 4, 6, 7; unusually high in No. 5, described by Russell as scoriaceous obsidian; still higher in the perlites Nos. 8, 11; and reach a maximum in the pitchstones Nos. 9 and 10.

Basic glasses are seldom sufficiently free from included crystals to be separable from the porphyritic rocks. Frothy and cellular crusts do, however, appear on lava streams, and are known as scorias, and rare, homogeneous glasses have been called tachylyte and hyalomelane.

Varieties. — The chief glasses are obsidian, pumice, perlite and pitchstone. The name obsidian is applied to homogeneous glasses with low percentages of water. The word is of classic and ancient origin and is now used with a prefixed name for all glasses, such as rhyolite-obsidian, basalt-obsidian, etc. Pumice is an excessively cellular glass, caused by expanding steam bubbles. Perlite is a glass broken into small onion-like, individual masses, by concentric cracks, from contractions in cooling. The concentric, shelly masses lie in between intersecting series of larger, straight cracks; the perlites have considerable water, usually 2–4 per cent. The word is also written pearlstone, and was suggested by the fancied resemblance of the concentric shells to the familiar gem. Pitchstone is a homogeneous glass, like obsidian, but contains 5–10 per cent. of water. Pitchstones have often a more resinous appearance than obsidians, but there is no very essential difference apparent to the eye. The name was formerly used for glasses of earlier geological age than the obsidians. Obsidians are usually black or red, with translucent edges; pitchstones are mostly reds and greens, but thin slivers are practically colorless; all the glasses contain dusty, embryonic crystals, gas pores, and sometimes skeleton crystals of larger growth and even a few phenocrysts which are often arranged in flow lines and swirling eddies. Almost all large developments of the glasses show dense, stony or lithoidal layers and streaks, that are due to the development of minute crystals of feldspar and quartz, which may be arranged in radiating rosettes, called spherulites. The individual crystals are not often large enough to be seen with the unassisted eye. Expanded, bubble-like cavities are also met, with perhaps several concentric

walls, on which at times are perched little well-formed crystals. These cavities are called lithophysæ, *i. e.*, stone bubbles. Topaz, quartz, tridymite, feldspars, fayalite and garnet have been found in beautiful crystals in them. The lithophysæ are due to the influence and escape of mineralizers, and may reach a diameter of over an inch.

Relationships. — The glasses are all mere varieties of volcanic rocks, which a quick chill has prevented crystallizing. At the same time, it is only possible by field associations or by chemical analysis to refer them to their corresponding porphyritic types, although in the great majority of cases they are formed from rhyolitic magmas.

Geological Occurrence. — The glasses sometimes appear as independent sheets and dikes; more often they form the surface of well crystallized lava-sheets or the outer portions of dikes.

Alteration. — Glasses resist alteration notably well, but in the long run are subject to decay along cracks and exposed surfaces. They yield quartz, kaolin and fine, scaly muscovite. In instances they devitrify, as it is called, or break up into aggregates of quartz and feldspar in excessively minute crystals, so that we can only trace them back to the original glass, by the flow lines, spherulites, etc., that still remain. Such devitrified forms have been called by F. Bascom, apobsidian. Petrosilex is an older term applied to these and other similar rocks, and felsite has been also used.

Distribution. — The glasses are widespread in the West. Obsidian Cliff, in the Yellowstone Park, yields black, red and stony varieties, and has been made a type locality by the studies of J. P. Iddings. Silver Cliff, Colorado, has furnished some remarkable pitchstones, described by Whitman Cross. The extinct volcanoes of New Mexico, Utah, Montana and around Mono Lake, California, are well-known localities. Alaska has supplied much from near Fort Wrangel, and in Mexico and Iceland are other prolific sources. Along the Atlantic Coast there are only the devitrified glasses of ancient (pre-Cambrian) volcanoes. These are well developed in New Brunswick, Maine, Massachusetts and Pennsylvania. Abroad the obsidian of the Lipari Islands is a famous one, and the perlites of Hungary supply the usual type

specimens in our collections. The best known of all pitchstones are found at Meissen, near Dresden, in Saxony, and on the island of Arran, off the west coast of Scotland.

THE RHYOLITE–GRANITE SERIES.

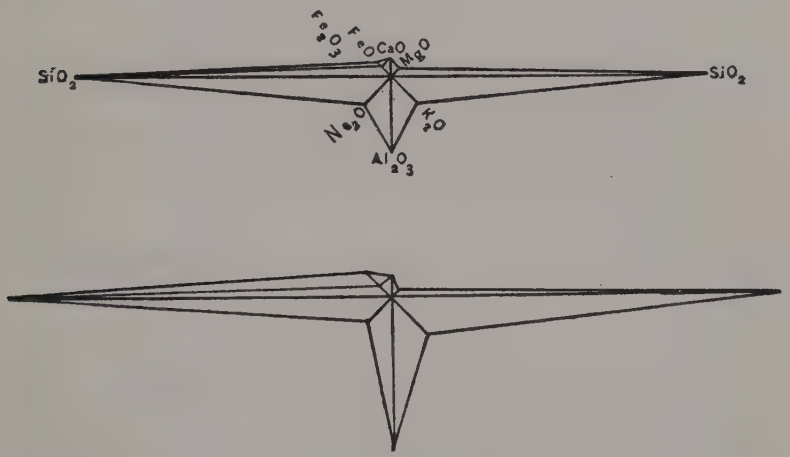
The Rhyolites.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	Loss.	Sp. Gr.
1.	78.95	10.22	3.23	...	1.84	0.14	1.76	4.18		
2.	77.5	9.7	6.1	...	...	...	5.8	0.3	0.4	
3.	75.20	12.96	0.37	0.27	0.29	0.12	8.38	2.02	0.58	
4.	73.91	15.29	...	0.89	0.77	...	4.79	3.62	1.19	
5.	73.07	11.78	2.30	...	2.02	0.39	6.84	1.19	2.24	
6.	71.12	14.58	1.69	...	1.50	0.15	6.01	3.26	0.95	
7.	70.92	13.24	3.54	0.66	1.42	0.23	4.25	4.28	0.57	
8.	70.74	14.68	0.69	0.58	4.12	0.28	2.59	2.29	2.09	2.68
9.	68.84	15.73	...	3.11	3.58	0.90	3.59	2.89	1.50	2.4
10.	68.10	14.97	2.78	1.10	3.04	1.10	2.93	3.46	1.28	2.636
11.	67.20	14.95	5.19	...	0.30	2.39	0.89	4.00	2.13	
12.	66.91	14.13	5.00	...	2.35	0.95	5.40	3.86	1.42	
13.	66.60	16.69	2.06	0.93	1.40	1.15	5.23	2.46	1.70	2.43
14.	63.63	17.42	0.15	5.76	2.86	...	5.54	4.52	0.15	

1. Rhyolite, Iceland, Bäckström, Contrib. to Icelandic Liparites. 2. Rhyolite, Wales, A. Harker, Bala Volc. Ser., 13. 3. Rhyolite, Silver Cliff, Colo., Cross, Colo. Sci. Soc., Dec. 5, 1887, 229. 4. Rhyolite, Pinto Peak, Eureka, Nev., A. Hague, Mono. XX., 264. 5. Rhyolite, McClelland Peak, Washoe, Dist., Nev., F. A. Gooch, Bull. 17, U. S. G. S., 33. 6. Rhyolite, Island of Ponza, near Naples, quoted by Kalkowsky, Elem. d. Lith., p. 75. 7. Rhyolite, Yellowstone Park, Iddings, Origin Igneous Rocks, Tab. 1. 8. White Rhyolite Porphyry, Leadville, Colo., Cross, Mono. XII., U. S. G. S., 326. 9. Rhyolite, Lassen's Peak, Cal., Fortieth Paral. Survey, I., 652. 10. Gray Rhyolite Porphyry, Leadville, Colo., Mono. XII., U. S. G. S., 332. 11. Rhyolite Porphyry, Flagstaff Hill, Colo., Palmer & Fulton, Colo. Sci. Soc., III., 356. 12. Rhyolite, Hungary, v. Hauer, Verh. d. k. k. R., 1867, 118. 13. Rhyolite Porphyry, Upper Quinnesec Falls, Mich., G. H. Williams, Bull. 62, U. S. G. S., 120. 14. Rhyolite Porphyry, Waterville, N. H., G. W. Hawes, N. H. Geol. Surv., III., 178.

Comments on the Analyses. — The analyses illustrate the ranges of the various molecules. No. 1 illustrates the upper limit of the percentages of SiO_2 and No. 2 the lower limit of Al_2O_3. The gradual increase of Al_2O_3 in all the others, with decrease of SiO_2, and in general the same relation as regards CaO are worthy of remark, as is the prevailingly low MgO. Sometimes K_2O, sometimes Na_2O, is in excess, and this brings out the reason why we speak of orthoclase as the chief feldspar, not as the only one, in the table, p. 23. The specific gravity is in general low.

Fig. 8 is a diagram based upon the molecular ratios obtained from those analyses, given above, which contain determinations both of Fe_2O_3 and FeO. Lengths proportionate to the molecular ratios have been laid off upon the radiating arms and have then been connected by the bounding lines. As the molecular ratio of silica is much the largest of those used it has been halved and the



FIGS. 8 AND 9. Diagram illustrating the chemical composition of the rhyolites whose analyses are given in the above table. Fig. 8 is based on molecular ratios; Fig. 9 on percentages.

halves have been laid off on the horizontal line, each way from the middle point. The resulting figure, with its long arms for silica, its quite long arms for alumina and the alkalies, and its short ones for lime, iron and magnesia, is very characteristic and its significance will be the more evident when compared with the diagrams which follow. Fig. 9 has been drawn in the same way but the percentages obtained by averaging the same analyses which were used for the molecular ratios in Fig. 8 have been employed. In a general way the figures resemble each other, but those oxides whose molecular weights are high, such as iron, have relatively shorter arms in Fig. 8 than in Fig. 9. Fig. 9 is given so as to accustom the student to pass from percentages, with which he is familiar, to molecular ratios to which he is usually relatively unaccustomed; and yet as explained on page 19 the latter are the more significant in the chemistry of rocks.

General Description.—The Rhyolite Series embraces a large and diversified group of rocks. All its members have the light-colored minerals, quartz, orthoclase and plagioclase in great excess. The dark-colored minerals, biotite, hornblende and augite, of which biotite is the commonest, are greatly in the minority. This is most emphatically shown in the more acidic members, but while always pronounced the disparity is less marked in those with the lower percentages of silica. The accessory minerals, magnetite, hematite, pyrite, etc., are few and inconspicuous. The prevailing colors are light grays, yellows and pale reds, but darker shades especially of red are not uncommon. The rhyolites have high fusing points ranging above 1200° C. (2200° F.). When molten they are therefore usually viscous and thick and their movements are not marked by the fluidity shown by the more basic rocks. Hence, when solidified they often exhibit the flow lines still preserved, which originally suggested their name from the Greek verb meaning to flow.

The textures of the rhyolite series vary widely and upon them are based the principal varieties. The *Rhyolites proper* are felsitic or moderately porphyritic rocks, often somewhat cellular because of their typical occurrence in surface-flows, whose dissolved vapors have expanded under the comparatively slight pressure of the atmosphere and have caused the cavities. Spherulites, lithophysæ and the minerals which are characteristic of the latter are often found in rhyolites. When the texture is felsitic it may be impossible to distinguish and recognize the small component minerals, even with a lense, and then the rocks must be identified by their light color and specific gravity. Such rhyolites are sometimes described as lithoidal, and the microscope has shown that their component minerals are minute quartzes and feldspars, often with some glass. If in doubt as between rhyolites and trachytes or dacites the non-committal term felsite is then often convenient. With the development of phenocrysts the exact determination of the rock becomes less difficult. Quartz and the feldspars are the prominent ones, the dark silicates often being scarcely apparent. The groundmass is usually felsitic but it may be glassy. The phenocrysts exhibit their characteristic crystal forms unless rounded by corrosion. The quartzes are double six-sided pyramids, almost never with a visible prism.

The *Rhyolite Porphyries* have abundant phenocrysts. The cellular texture disappears and dense felsitic groundmasses are the rule. The phenocrysts in typical cases make up about half the rock. These textures are characteristic of the central portions of thick surface flows, and of dikes, intruded sheets and the outer parts of laccoliths.

The *Granite Porphyries* result when the phenocrysts are in marked excess over the groundmass and constitute the greater part of the rock. The groundmass is felsitic but becomes increasingly coarsely crystalline, as these rocks approximate the granites. The granite porphyries occur in deep-seated dikes, thick intruded sheets and the central portions of laccoliths. They mark a textural transition to the granites.

Synonyms and Relatives.—The name rhyolite was first given by von Richthofen in 1860 to the rocks which had previously been called quartz-trachytes. About a year afterward Justus Roth suggested liparite for the same group, a name derived from the Lipari Islands between Naples and Sicily, where these rocks are characteristically developed, and liparite in consequence is much used by European geologists. When both these names were applied, and first used, they were intended for Tertiary and later eruptives alone. The pre-Tertiary representatives were called quartz-porphyries. With the disappearance of this time-distinction quartz-porphyry became restricted to the intrusive dikes and sheets with their dense textures as contrasted with the rhyolites proper or surface flows. It is practically a synonym of rhyolite-porphyry as used here, which is also a term long current, the latter expression admitting as it does of analogous and uniform names all through the series of igneous rocks. A synonym of granite-porphyry as here used is nevadite, a word suggested by von Richthofen for those rhyolites with an excess of phenocrysts. Recrystallized and usually more or less silicified rhyolites which have suffered metamorphism in the long course of geologic time have been called by F. Bascom, aporhyolites.

Certain close relatives of the rhyolite series which are rich in soda and whose feldspar is thus anorthoclase have been called quartz-pantellerites from the island of Pantelleria in the Mediteranean, off the coast of Spain, and their pre-Tertiary equivalents

quartz-keratophyrs. They cannot be distinguished from the rhyolite series without the microscope. Fuller details are given in the Glossary, where will also be found grorudite, paisanite and several others.

Relationships. — Rhyolites pass by insensible gradations into glasses on one side, trachytes on another, granites on a third and dacites on a fourth. Without the microscope rhyolites can only be identified with certainty by recognizing the quartz, and may then be confused with dacites. The striated feldspar of the latter is our chief means of distinction between the two.

Alteration.—Ordinary decay leads to the formation of clays and kaolin. In metamorphic alterations the rhyolites pass into very finely crystalline aggregates of quartz and feldspar, and then it is difficult to decide what minerals are original and what secondary, and whether the original rock was a massive one or a tuff. Shearing stresses develop schistose structures, and when decay is further superadded, sericite schists may result that are extremely difficult geological problems.

Distribution. — Rhyolites are common in the Western States. being well known in the Black Hills: the Yellowstone Park; in Colorado, where Chalk Mountain, near Leadville, is a type locality for nevadite (granite porphyry); in Nevada, both near Eureka and near the Comstock lode, and in California. The rhyolite-porphyries have been met in many Western districts, but are of especial importance at Leadville, where they are intimately associated with the ores. The ancient rhyolite-porphyries have also an important development on Lake Superior. The greater part of the boulders in the Calumet copper-bearing conglomerate consists of them, and Lighthouse Point, near Marquette, furnishes an outcrop. Along the Atlantic Coast the pre-Cambrian rhyolites (felsites) are present in the same localities as those cited for volcanic glasses. Recent rhyolites are in vast quantity in Iceland. Many are known in Europe, but the enormous development in Hungary is especially worthy of note. The sheets of rhyolite on the Lipari Islands between Naples and Sicily suggested the name liparite. In almost all volcanic districts they are liable to occur. In the Tyrolese Alps rhyolite-porphyries are of great extent, and in Scandinavia

and in Cornwall, they form important dikes, familiar to all students of the subject.

Rhyolite Tuffs.—These are the fragmental ejectamenta from explosive eruptions that often afford very extensive strata of rock. Although loose at the time of falling, they may become consolidated in the course of time, or before this occurs they may be sorted and redeposited in water so as to share the nature of a true sediment. Fragments of volcanic glass and of all the component minerals of rhyolite make them up, while larger fragments of rock and volcanic bombs are at times intermingled. Tuffs of ancient geological date become metamorphosed and recrystallized, so as to afford products not to be easily distinguished from compact felsites.

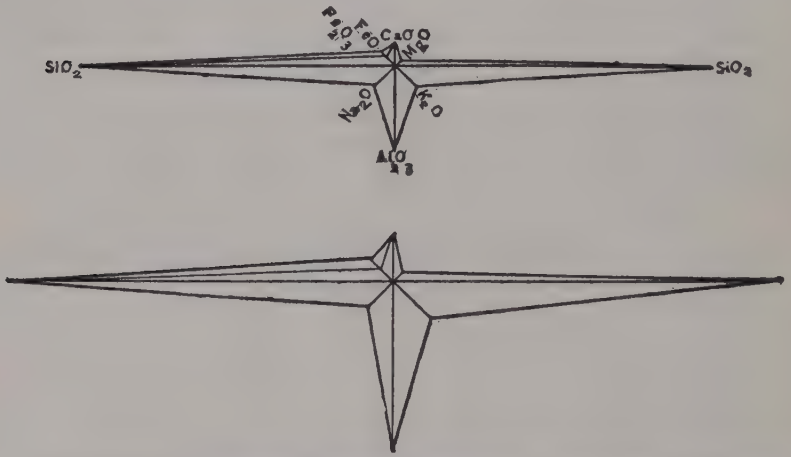
Rhyolite tuffs are abundant along the eastern foothills of the Front Range of Colorado, and are extensively quarried for a rather soft, building stone.

The Granites.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	Loss	Sp. Gr.
1.	73.76	13.43	1.16		1.42	0.75	5.22	4.01	0.42	2.63
2.	73.70	14.44	0.43	1.49	1.08	tr.	4.43	4.20	0.40	2.69
3.	73.05	14.53	2.96	.....	2.06	tr.	5.39	1.73	0.29	
4.	72.73	16.95		.....	1.05	tr.	8.15	0.90	0.22	
5.	72.26	13.59	1.16	2.18	1.13	0.06	5.58	3.85	0.47	2.65
6.	71 78	14.75	.....	1.94	2.36	0.71	4.89	3.12	0 52	
7.	71.64	15.66	2.34	.....	2.70	tr.	5.60	1.58	0.48	
8.	69.46	17.50	2.30	.....	2.57	0.30	4.07	2.93	0.82	2.687
9.	69.28	17.44	2.30	.....	2.30	0.27	2.76	3.64	.....	
10.	68.68	16.28	0.66	2.55	2.24	0.81	4.07	2.88	0.85	
11.	66.84	18.32	2.27	0.20	3.31	0.81	2.80	5.14	0.46	
12.	66.68	14.93	1.58	3 23	4.89	2.19	2.05	2.65	1.25	
13.	66.40	17.13	.....	3.77	1.65	0.94	2.08	4.49	1.03	

1. Biotite granite, Green's Landing, Me., E. F. Hicks. Privately communicated. 2. Granitite, Peterhead, Scotland, Phillips, Q. J. G. S., XXXVI., 1880, 13. 3. Red Granitite, Westerly, R. I., F. W. Love, for J. F. K., Bull. Geol. Soc. Amer., X., 375. 4. Red Granite, Stony Point, Conn., L. P. Kinnicut, Anal., Idem. 5. Albany granite, N. H., Hornblende granite, G. W. Hawes, A. J. S., iii., XXI., 25. 6. Hornblende granite with biotite, Cottonwood Cañon, Utah, T. M. Drown, 40th Parallel Surv., I., 110. 7. Gray granitite, Westerly, R. I., see No. 3. 8. Typical granite, Chester, Mass., L. M. Dennis, for J. F. K., N. Y. Acad. Sci., XI., 129. 9. Biotite granite, Raleigh, N. C., G. P. Merrill, Stones for building and decoration, 418. 10. Biotite granite with hornblende, Wood Cone, Eureka Dist., Nev., Arnold Hague, Mono. XX., U. S. G. S., 228. 11. Augite-soda granite, Kekequabic Lake, Minn., U. S. Grant, Amer. Geol., June, 1893, 385. 12. Granitite, Rowlandville, Md., G. P. Grimsley, Jour. Cin. Soc. Nat. His., 1894, p. 32. 13. Biotite granite with hornblende, El Capitan, Yosemite, see No. 6.

Comments on the Analyses. — These analyses illustrate the general range of SiO_2, but granites are known outside of both limits. As SiO_2 decreases the bases increase, and soda tends to exceed potash, marking the passage to the diorites. Those high in Na_2O, like No. 11, are often called soda-granites. They are analogous to the keratophyres, soda-rhyolites and pantellerites, earlier referred to. The whole table is a close parallel to that of the rhyolites. The analyses are selected, so far as possible, to represent prominent building stones.



FIGS. 10 AND 11. Diagrams illustrating the chemical composition of the granites given in the above table. Fig. 10 is based on molecular ratios; Fig. 11 on percentages.

Figs. 10 and 11 have been drawn upon the basis of the average molecular ratios and percentages of the above analyses as was explained under the rhyolites. The figures are practically the same as those for the rhyolites.

Mineralogical Composition and Varieties. — Granites are, preëminently, granitoid rocks consisting of orthoclase, sometimes microcline, some acid plagioclase, quartz, and in the typical variety both biotite and muscovite. The light colored minerals are in marked excess. Magnetite, apatite and zircon are always present, though small, and garnet is not at all unusual. Biotite is much the commoner of the micas, and when it is present alone the rock is sometimes called granitite. Granites with muscovite alone are especially found in the form of dikes. They are called aplite. Hornblende is

also frequently met, either with biotite or by itself, giving then hornblende-granite. In former years this aggregate was called syenite, but the modern usage is different. Augite in granites is uncommon, and marks a passage to the gabbros. All forms of dark silicates and mica may fail, and then we have the so-called binary granites. Some Missouri granites are of this character.

Especially in regions of granite intrusions and of extensive metamorphism, veins or dikes — it is an open question which is the more correct term — are met, which are formed of very coarsely crystalline aggregates of the same minerals that constitute granite. These are called pegmatite and in them is the home of graphic granite, the curious intergrowth of quartz and feldspar, such that a cross fracture of the blades of quartz suggests cuneiform characters. Garnet, tourmaline, beryl and minerals involving the rare earths, are often found in pegmatites, and they supply the feldspar and mica of commerce. The outcrops may be two hundred feet broad or more, and again the same aggregates are found as small lenses or "Augen" in metamorphic rocks. In regard to the larger veins or dikes it seems improbable that true igneous fusion could have afforded such coarsely crystalline aggregates, and so we are forced to assume such abundance of steam and other vapors, *i. e.*, mineralizers, as to almost, if not quite, imply solution.

The fusing point of granite has been determined at about 2250° F. (1240° C.), but it would of course vary with the composition, being highest in those richest in silica.

The outer portions of granite masses are often subjected to the action of escaping vapors, containing boracic and hydrofluoric acids. These develop tourmaline in quantity and often fluorite, and in rare instances cassiterite. In a famous case near Luxullian, in Cornwall, the feldspar has become changed to an aggregate of tourmaline needles and quartz, and the rock is called luxullianite. Tourmaline granite is, however, also known in which tourmaline plays the rôle of mica or hornblende, as at Predazzo, in the Tyrol. The vapor may change the borders of granites to a mass of quartz and a lithia mica, affording the rock that is called greisen and that is a familiar gangue for tin ores.

Granites are commonly gray, bluish or reddish in color. The feldspar is mainly responsible for this, as quartz is colorless and

transparent and biotite and hornblende are not specially abundant; but unusual richness in the last named silicates tends to darken the shade. These latter are very frequently segregated into the black bunches that are noticeable in many building stones. The dark minerals may assume concentric layers, affording so-called orbicular granite.

Relationships. — The passage of granites, through granite-porphyries and micro-granites, into rhyolite-porphyries and felsites, has been remarked. Sometimes along the border of an intrusion, this can be traced inch by inch to a place where the porphyritic texture is due to a quick chill. Mt. Willard, in the Crawford Notch of the White Mountains is a classic locality for this transition. It was described in 1881 by Geo. W. Hawes (see analysis 6), and will be referred to again under the products of contact metamorphism. The close relationship of the granite porphyries or nevadites with granite need only to be referred to. As quartz decreases, syenites result by insensible gradations, and as hornblende or biotite and plagioclase increase, the same passage is made to diorites. Intermediate varieties, which are very common, are often called granite-diorites or grano-diorites. Transitional passages to gabbro, from increase of augite and plagioclase, are also well recognized.

Geological Occurrence. — Granites in their most typical development constitute great irregular masses that have solidified at depths; such are called batholiths, and it is generally believed that before consolidating they have often fused their way upward by melting into themselves overlying rock. Granites also appear as irregular or rounded outcrops in the midst of other rocks (bosses or knobs) and as dikes. There is no reason why granites should not form at all geological ages, but those open to our observation are mostly Archean and Paleozoic because, being deep-seated rocks, only the older ones have been exposed by erosion. The relations of pegmatites to veins have been earlier set forth. Granites tend to break apart along jointing planes into rectangular blocks, a property that much facilitates their quarrying. They also have lines of weakness admitting of their further division into smaller masses. The development of these is more or less characteristic of each particular locality.

Uses. — Granites are much more extensively employed for structural purposes than any other igneous rock, and indeed in the trade any crystalline rock consisting of silicates is called granite. They are in general the strongest of the common building stones. Crushing resistances range from 10,000 to 25,000 pounds per square inch in a 2-inch cube. The important points are homogeneity of texture, good, rectangular cleavages in the quarry, adaptability to tool treatment, durability and pleasing color.

Alteration, Metamorphism. — In ordinary decay granites suffer first by the oxidation of the protoxide of iron in the ferromagnesian silicates (biotite, hornblende), and the formation of chlorite and other secondary minerals. The feldspars also kaolinize, and the rock thus becomes hydrated. Pyrite, if present, is an active agent in decay. Yet the chemical changes involved, except hydration, seem to be comparatively slight even in the change from granite to soil. G. P. Merrill gives the following analyses of unaltered and altered biotite granite from the vicinity of Washington, D. C. (*Bull. Geol. Soc. Amer.*, VI., 323):

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	Ignition.
1.	69.33	14.33	...	3.60	3.21	2.44	2.67	2.70	1.22
2.	66.82	15.62	1.88	1.69	3.13	2.76	2.04	2.58	3.27
3.	65.69	15.23	4.39		2.63	2.64	2.00	2.12	4.70

No. 1 is fresh and undecomposed rock; No. 2, decomposed but still moderately firm rock; No. 3, soil. It is evident at once that there has been considerable hydration, and that a notable decrease in the alkalies has occurred, each being affected about equally in the end, although K_2O yields first; MgO has relatively increased; CaO has suffered loss; the FeO is all oxidized, the Al_2O_3 has relatively increased and the SiO_2 decreased. While appreciating these chemical changes, Dr. Merrill still emphasizes the much greater importance of the physical alteration and attributes this to swelling from hydration. Other interesting data are given in the citation. Similar sets of parallel analyses have been made abroad with analogous results in the case of the chemical rearrangements.

Under dynamic stress granites are more or less crushed and have their minerals drawn out into laminations from shearing strains so that they readily assume gneissoid structures. Beyond question many gneisses have resulted in this way, and in the geol-

ogy of some districts, as, for instance, the Front Range of Colorado, we employ the term granite-gneiss. The structures were, doubtless, induced while the granite was deeply buried and subjected to pressure when closely confined, so that the yielding came in a gradual flow.

Distribution. — Granites are abundant along the Atlantic coast, and are near tidewater from Canada to Virginia. Farther south they lie back of the Coastal Plain. They are chiefly biotite granite and are extensively quarried. A famous hornblende granite is obtained at Quincy, Mass., and was formerly called syenite. In the old crystalline areas of Michigan, Wisconsin and Minnesota they are common. Missouri has many in the region of the porphyries, already cited. In the West, the Black Hills, the Rocky Mountains, the Wasatch and the Sierras are abundantly supplied. They are equally common in Europe and elsewhere the world over.

The Rhyolite-Granite Table. — In the following table and the three other similar ones which later appear, representative analyses have been selected from those used in the descriptive text. They have then been recast according to the methods described under Chapter XIII., so as to obtain the percentage by weight of the component minerals of the rock. These are given under the column Wt. The percentages by weight have then been divided by the respective specific gravities of the several minerals, the quotients being proportional to the volumes of the minerals in the rock. The quotients are then reduced to percentages so that under the column headed Vol. we see the proportion of the rock mass made up of each mineral. These values are of especial significance in connection with sight determinations. Necessarily minerals with low specific gravities have, as compared with percentages by weight, relatively increased percentages by volume; whereas minerals of high specific gravities relatively decrease. Contrasted proportions of light-colored and dark-colored minerals are also given since they are all-important in the general impression given by a rock. The calculations unavoidably involve assumptions at times but are on the whole, correctly representative. As explained under Chapter XIII., difficulties arise where an oxide appears in two different minerals as when K_2O is in both orthoclase and biotite.

Rhyolite.

	28.3*		28.7		28.10		28.13		28.14	
SiO_2	75.20		70.92		68.10		66.60		63.63	
Al_2O_3	12.96		13.24		14.97		16.69		17.42	
Fe_2O_3	.37		3.54		2.78		2.06		.15	
FeO	.27		.66		1.10		.93		5.76	
MgO	.12		.23		1.10		1.15			
CaO	.29		1.42		3.04		1.40		2.86	
Na_2O	2.02		4.28		3.46		2.46		4.52	
K_2O	8.38		4.25		2.93		5.23		5.54	
Loss	.58		.57		1.28		1.70		.15	
Total	100.19		99.11		98.76		98.22		100.03	
	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.
Quartz	31.3	30.5	29.4	29.5	29.2	29.4	24.6	24.7	6.4	6.4
Orthoclase	48.4	49.1	17.8	18.7	15.6	16.2	27.8	29.2	32.8	34.2
Albite	16.8	16.5	36.2	37.1	29.3	30.0	21.0	21.5	37.7	38.6
Anorthite	1.4	1.3	6.9	6.7	15.0	14.4	7.0	6.7	10.8	10.4
Kaolinite	.3	.2		.8			11.1	12.3		
Biotite	1.0	.9	5.3	5.0	5.0	4.9	3.9	3.6		
Amphibole †									11.8	10.0
Magnetite	.5	.2	2.1	1.0	3.5	2.0	3.0	1.6	.3	.1
Ilmenite										
Water	.5	1.3	.5	1.2	1.2	3.1	.1	.4	.2	3
Totals	100.2	100.0	98.2	100.0	98.8	100 0	98.5	100.0	100.0	100.0
Light-colored Minerals	98.7	98.9	90.8	94.0	90.3	93.0	91.6	94.8	87.9	89.9
Dark-colored Minerals	1.5	1.1	7.4	6.0	8.5	7.0	6.9	5.2	12.1	10.1

Granite.

	33.2		33.5		33.10		33'12	
SiO_2	73.70		72.26		68.68		66.84	
Al_2O_3	14.44		13.59		16.28		18.32	
Fe_2O_3	.43		1.16		.66		2.27	
FeO	1.49		2.18		2.55		.20	
MgO	tr.		.06		.81		.81	
CaO	1.08		1.13		2.24		3.31	
Na_2O	4.20		3.85		2.88		5.14	
K_2O	4.43		5.58		4.07		2.80	
Loss	.40		.47		.85		.46	
Total	100.17		100.28		99.02		100.15	
	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.
Quartz	30.2	29.8	26.0	25.6	28.0	28.0	17.5	17.5
Orthoclase	22.3	22.9	32.9	33.8	22.2	23.3	13.9	14.5
Albite	35.6	36.0	32.6	32.7	24.6	25.3	43.3	44.2
Anorthite	5.3	5.0	1.4	1.3	11.1	10.7	16.4	15.8
Kaolinite	1.8	2.0			5.2	5.6		
Biotite	4.3	3.8			4.6	4.2	7.9	7.3
Amphibole †			4.8	4.0	2.3	2.0		
Magnetite	.5	.2	1.7	.9	.9	.5	.7	.4
Ilmenite			.9	.5				
Water	.2	.3	.5	1.2	.1	.4	.1	.3
Totals	100.2	100.0	100.8	100.0	99.0	100.0	99.8	100.0
Light-colored Minerals	95.4	96.0	93.4	95.1	91.2	93.3	91.2	92.3
Dark-colored Minerals	4.8	4.0	7.4	4.9	7.8	6.7	8.6	7.7

* The double numbers at the head of the columns refer to the page and the number of the analysis. Thus 28.3 means p. 28, analysis 3, and so on.

† Amphibole may include pyroxene.

Study of the Rhyolite-Granite table on p. 39 shows that the light-colored minerals are greatly in excess. The maximum percentage by volume is 98.9; the minimum 87.9. We may say therefore that rarely are quartz and feldspar less than nine tenths of the volume of these rocks. Quartz ranges from a maximum of 30.5 to a minimum of 6.4, but is in general over 20 per cent. Orthoclase has a maximum of 49.1 but with relative increase of albite (i. e., of soda) it may drop to 14.5. In the last-named case albite reaches its maximum of 44.2 — and in the former its minimum of 16.5. Anorthite rules low, 1.3 as a minimum, with an exceptional maximum of 15.8. Biotite has a minimum of .9 and a maximum of 7.3. Amphibole ranges from 2 to 10. Magnetite is usually less than 1, but has a maximum of 2. Although orthoclase yields at times to albite, the alkaline feldspars are always in great excess over the lime-soda varieties.

THE TRACHYTE-SYENITE SERIES.

The Trachytes.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	Loss.	Sp.Gr.
1.	66.03	18.49	2.18	0.22	0.96	0.39	5.86	5.22	0.85	2.59
2.	65.07	16.13	5.17	...	2.74	0.67	4.44	4.77	0.70	
3.	62.28	19.17	3.39	...	1.44	...	5.93	5.37	2.33	2.65
4.	62.17	18.58	2.15	1.05	1.57	0.73	3.88	7.56	1.70	
5.	58.70	19.26	3.37	0.58	1.41	0.76	4.53	8.55	2.64	
6.	57.7	17.9	4.4	3.9	3.7	1.8	7.7	3.8	0.1	2.61

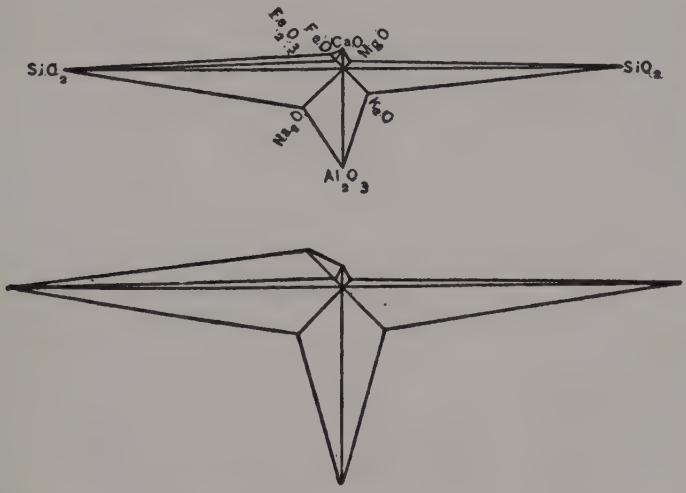
1. Trachyte, Game Ridge, Custer Co., Col., Cross, Proc. Col. Sci. Soc., 1887, 237. 2. Oligoclase-trachyte, Drachenfels on Rhine, Rammelsberg, Z. d. d. g. G., XI., 440. 1859. 3. So-called Bostonite dike, Lake Champlain, J. F. Kemp, Bull. 107, U. S. G. S., 20. 4–5. Acmite-trachyte, Crazy Mountains, Mont., Wolff and Tarr, Bull. Mus. Comp. Zoöl., XVI., 232. 6. Trachyte, Arso Flow, Ischia near Naples. Abich, Isola d'Ischia, 38. Silica determinations on eleven trachytes from the Black Hills afforded J. H. Caswell values from 65.46 to 52.02.

Comments on the Analyses. — The decrease in silica and the increase in alumina and the alkalies as against the rhyolites are noteworthy. The alkalies in particular are high, with sometimes potash, sometimes soda, in excess. The latter marks the passage to the phonolites.

Figs. 12 and 13 have been drawn respectively upon the basis of the average molecular ratios and of the average percentages of the above analyses. As compared with the figures of the rhyolite-

granite series they show shortened intercepts for silica, lengthened ones for alumina and the alkalies, and to a less degree for the other components.

General Description. — The Trachyte Series embraces a group of rocks of considerable diversity. All its members have the light-colored minerals in excess. The feldspars are much the most prominent components and give the pronounced character to the rock. Quartz practically fails although an occasional crystal may be seen. The passage from rhyolites to trachytes marks its disap-



FIGS. 12 AND 13. Diagrams illustrating the chemical composition of the trachytes which appear in the above table. Fig. 12 is based on molecular ratios; Fig. 13 on percentages.

pearance. Biotite is on the whole the most common of the dark silicates, but both hornblende and augite are well known. As with the rhyolites the prevailing colors are light grays, yellows and pale reds, with occasional darker shades. The trachytes have somewhat lower fusing points than the rhyolites, ranging somewhere about 2000° F. (1100° C.) and above. They therefore afford glasses much less often and less readily than the rhyolites, and show a greater tendency to appear as thoroughly crystalline rocks.

The textures of the trachyte series range from felsitic to coarsely porphyritic. The *Trachytes proper* are felsitic or moderately por-

phyritic rocks, sometimes cellular from their crystallization as surface flows. When finely felsitic they cannot readily be distinguished from rhyolites, dacites and andesites without microscopic examination, and then felsite is the only name which can safely be applied to them by the observer. Under the microscope the felsitic mass, whether forming the entire rock or only the groundmass, is very often found to be an aggregate of little rods of orthoclase arranged in more or less flowing lines and with their long dimensions parallel with one another. As groundmasses become coarser this peculiar texture can sometimes be detected with the eye alone and even in fairly coarse syenites it may be recognizable. It is characteristically known as the "trachyte texture."

With the development of phenocrysts, the exact determination of the trachytes becomes less difficult. Quartz fails and feldspars constitute the prominent porphyritic crystals. The greater number of the feldspars should show no striations when the cleavage faces are examined with a lense. The clear vitreous variety of orthoclase which frequently appears in the later volcanic rocks and especially in the trachytes was called sanidine by the early observers and the name sanidine is therefore often employed even to-day. Though visible, the dark silicates constitute but a subordinate part of the rock.

As the phenocrysts become abundant the trachytes proper pass into the *Trachyte-porphyries*. The groundmass is as a rule felsitic. The cellular texture disappears entirely and the rocks are dense and characteristically porphyritic. The interiors of thick surface flows, the dikes, intrusive sheets and the outer parts of laccoliths are their special home.

When phenocrysts are in marked excess over the groundmass and constitute the greater part of the rock, the *Syenite-porphyries* result. The groundmass is rather coarsely felsitic and becomes increasingly coarse as the true syenites are approached. All the minerals forming phenocrysts are now not difficult to recognize. The syenite-porphyries are met in deep-seated dikes, thick intrusive sheets and in the central parts of laccoliths. They mark a textural transition to the syenites.

Synonyms and Relatives.— The name trachyte is an old one, having been first given in 1822 by the Abbé Haüy to volcanic

rocks from the Auvergne in France, whose rough and rasping surfaces suggested its creation from the Greek adjective meaning rough. For thirty years or more it was used for the light-colored volcanic rocks which are now subdivided among the rhyolites, trachytes, dacites and andesites; and in earlier writers the word must often be interpreted in this general sense. For many years subsequent to 1860 and after its mineralogy became defined as now, it was restricted to the lavas of Tertiary and later age, while "porphyry" was employed for the corresponding rocks of earlier geologic time. Porphyry where accurately used is now little more than a textural term, but in common speech it is applied loosely to almost any eruptive which happens to be associated with an ore-body in the Cordilleran region. When soda becomes especially pronounced in the composition of a member of the trachyte series it leads to several mineralogical variations from the type. The principal feldspar may become anorthoclase, and then the name pantellerite has been applied. Acmite, the soda pyroxene, may appear, giving acmite-trachyte. Ægirite may manifest itself as may also sodalite. All of these however cannot readily be identified by the eye. They mark passages to the phonolites. Other names of interest in this connection are bostonite, keratophyre, volcanite, latite, vulsinite, trachyandesite, trachydolerite, etc., all of which will be found in the Glossary.

Alteration. — The alteration is practically the same as that described under rhyolites.

Distribution. — True volcanic trachytes are extremely rare in this country, for many of the other cited localities, as, for instance, some of those in the reports of the Fortieth Parallel Survey, have been shown to be andesites. Beautiful examples do, however, occur in the Black Hills, with superbly developed orthoclases. Others are known in Custer County, Col. (see Analysis 1), and in Montana (Analyses 4 and 5). The trachyte-porphyries, strictly so called, are not identified with certainty in very wide distribution, although, doubtless, many dikes in the West may be properly described as such. In southeast Missouri, at Iron Mountain and Pilot Knob, trachyte-porphyries are very abundant. Many interesting dikes of them occur around Lake Champlain, and among the pre-Cambrian volcanics of the Atlantic Coast they are not lacking. Abroad tra-

chytes are more common, and along the Rhine — where the peak of the Drachenfels is situated, which furnishes the commonest specimens for collection — in the Auvergne, in Italy and in the Azores they are well known.

Trachyte Tuffs are not common in America, and offer only microscopic points of difference from those formed of rhyolitic material.

THE SYENITES.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	Loss.	Sp. Gr.
1.	60.03	20.76	4.01	0.75	2.62	0.80	5.48	5.96	0.59	
2.	59.83	16.85		7.01	4.43	2.61	6.57	2.44	1.29	2.73
3.	59.78	16.86	3.08	3.72	2.96	0.69	5.01	5.39	1.58	2.689
4.	59.37	17.92	6.77	2.02	4.16	1.83	6.68	1.24	0.38	2.71
5.	56.45	20.08	1.31	4.39	2.14	0.63	7.13	5.61	1.77	
6.	46.11	14.75	2.20	4.51	7.82	5.73	3.84	1.29	1.59	2.904
7.	46.73	10.05	3.53	8.20	13.22	9.68	3.76	1.81	1.24	

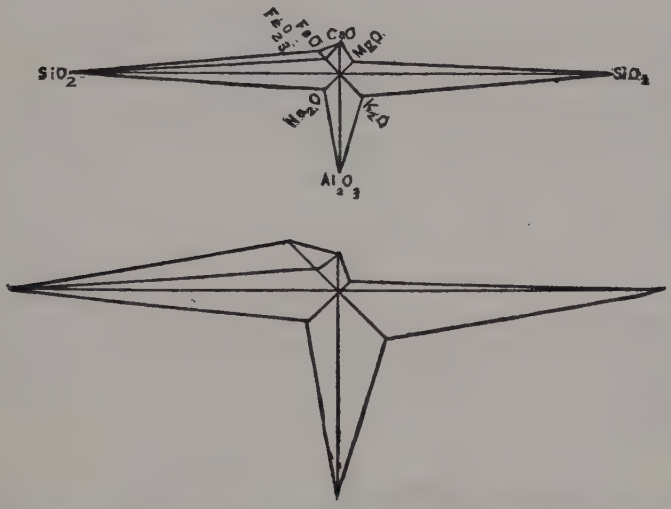
1. Fourche Mtn. near Little Rock, Ark., J. F. Williams; Igneous Rocks of Ark., 88. 2. Plauen, near Dresden, F. Zirkel, Pogg. Ann., CXXII., 622. 3. Custer Co., Colo. Cross, Proc. Colo. Sci. Soc., 1887, 240. 4. Biella, Piedmont, Cossa., Turin Acad., ii., XVIII., 28. 5. Sodalite-syenite, Highwood Mtns., Mont., W. Lindgren, A. J. S., Apr., 1893, 296. 6. Minette, Rhode Island, badly decomposed, contained CO_2 7.32, Pirsson, A. J. S., Nov., 93, 375. 7. Shonkinite, Highwood Mtns., Mont., Weed and Pirsson, Bull. Geol. Soc. Amer., VI., 414.

Comments on the Analyses. — The syenites mark a decrease in SiO_2 from the granites and a general increase in all the bases. The high percentage of alkalies is especially worthy of remark, and the notably large amounts of soda, showing the passage to the nepheline syenites. The parallelism with the trachytes is close. The last two analyses exhibit excessively basic extremes, whose theoretical significance is commented on in the next paragraph.

Figs. 14 and 15 are based respectively upon the average molecular ratios and the average percentages of the above analyses except Nos. 6 and 7. They show interesting contrasts with Figs. 10 and 11 of the granites, being shortened right and left, and lengthened above and below. The figures are almost the same as those of the trachytes.

Mineralogical Composition, Varieties. — The name syenite was suggested by Syene, now Assuan, an Egyptian locality, where a hornblende granite was formerly obtained for obelisks, and if its local significance were perpetuated, syenite as formerly should be applied to this rock. But Werner used it in the last century for

the well-known typical rock from the Plauenschen Grund (see Analysis 2), near Dresden, that contains almost no quartz, and of recent years this has been its correct use. Typical syenites have orthoclase and hornblende; those with biotite are called mica-syenites. Some plagioclase is always present and magnetite, apatite and zircon are invariable. When the plagioclase becomes equal in amount with the orthoclase the rocks are called monzonites and they mark a transition to the diorites. Mica syenites in dikes,



FIGS. 14 AND 15. Diagrams illustrating the chemical composition of the syenites whose analyses appear in the above table. Fig. 14 is based on molecular ratios; Fig. 15 on percentages.

basic and of dark color, have been called minette. Orthoclase and augite afford augite-syenite. An excessively basic one (Analysis 7), from the Highwood Mountains, Mont., has recently been described by Weed and Pirsson under the name Shonkinite. It is of great theoretical importance, as it shows that orthoclase is not limited to acidic rocks, but may be the prevailing feldspar in very basic ones. Still more recently J. P. Iddings has noted others of similar character from the region of the Yellowstone Park. (Jour. of Geology, December, 1895, 935.) Basic nephelite-syenites have been earlier known. Still the table on page 23 expresses the general truth, the exceptions being excessively rare rocks so far as yet known. Syenites are themselves rare rocks. With high soda,

the mineral sodalite develops and yields sodalite syenites which are passage forms to nephelite syenites.

Relationships. — Syenites are most closely allied with nephelite-syenites, into which with increase of soda they readily pass. They also with increasing plagioclase shade into diorites and the augite-syenites are closely akin to gabbros.

Geological Occurrence. — Syenites form irregular masses and dikes, precisely as do granites.

Alteration. — There is little to be said that was not covered under granite. The rarity of syenite makes it a much less serious factor. In metamorphism they pass into gneisses.

Distribution. — Syenites occur in the great igneous complex of the White Mountains. They form large knobs and dikes near Little Rock, Ark., and a dike is known in Custer County, Colo. One of the few American minettes yet discovered is a dike on Conanicut Island, R. I., described by Pirsson (see Analysis 7). Abroad, syenites are better known. The Plauenscher Grund, near Dresden, Biella in the Piedmont, and the vicinity of Christiania, Norway, are the best known. Minettes are especially famous in connection with the mining district about Freiberg, Saxony, and in the Vosges mountains.

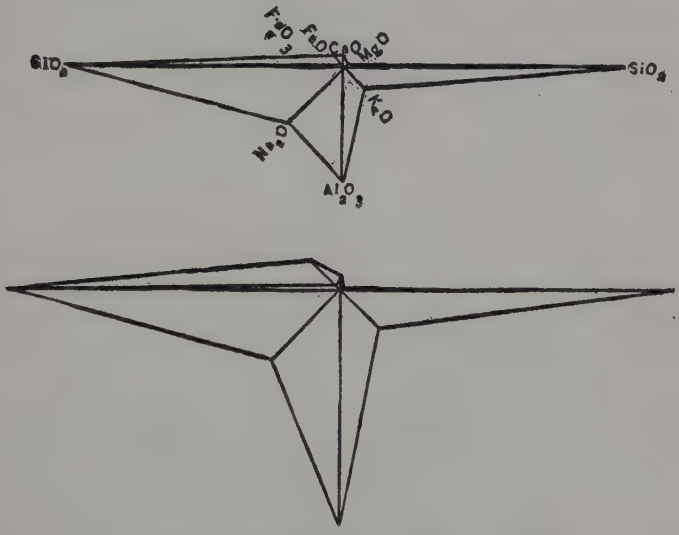
THE PHONOLITE–NEPHELITE–SYENITE SERIES.

The Phonolites.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	Loss.	Sp. Gr.
1.	61.08	18.71	1.91	0.63	1.58	0.08	4.63	8.68	2.21	2.582
2.	60.02	20.98	2.21	0.51	1.18	tr.	5.72	8.83	0.70	2.576
3.	59.46	23.00	3.52	...	1.00	0.50	4.90	7.13	0.71	
4.	59.17	19.74	3.39	...	0.92	0.15	6.45	8.88	1.18	2.566
5.	56.43	22.25	2.66	0.97	1.41	tr.	2.77	11.12	2.05	2.54
6.	49.18	20.65	...	5.97	2.43	0.29	6.88	9.72	1.60	2.553
7.	45.18	23.31	6.11	...	4.62	1.45	5.94	11.17	1.14	
8.	44.50	22.96	6.84	...	8.65	1.65	4.83	6.70	2.06	

1. Mato Tepee or Devil's Tower, near Black Hills, Wyo., Pirsson, A. J. S., May, 1894, 344. 2. El Paso Co., Colo., Cross, Proc. Col. Sci. Soc., 1887, 169. 3. Island of Fernando de Noronha, Brazil, Gümbel, Tscher. Mitt., 1880, II., 188. 4. Near Zittau, Saxony, v. Rath, Z. d. d. g. G., VIII., 297. 5. Wolf Rock, Cornwall, Eng., Phillips, Geol. Mag., VIII., 249. 6. Leucite-phonolite, near Rieden, Germany, Zirkel, Lehrbuch, II., 465. 7. Eleolite-porphyry, Beemerville, N. J., J. F. Kemp, N. Y. Acad. Sci., XI., 69. 8. Eleolite-porphyry, Magnet Cove, Ark., J. F. Williams, Igneous Rocks of Ark., 261.

Comments on the Analyses. — It is at once apparent from the analyses that the range in silica, except in the last two, is much like that of the trachytes, but that the alumina goes higher, and that the alkalies are in extremely large amounts. No other rocks, except the corresponding granitoid types, reach these amounts in alkalies. The soda which is necessary for the formation of the nepheline is naturally in excess. The rare leucite-phonolites, as a general thing, are more basic and show comparatively high potash. The last two analyses of intrusive or dike members are abnormally basic for phonolitic rocks.



FIGS. 16 AND 17. Diagram illustrating the chemical composition of the phonolites whose analyses appear in the above table. Fig. 16 is based on molecular ratios; Fig. 17 on percentages.

Figs. 16 and 17 are based respectively upon the average molecular ratios and the average percentages of the first five analyses in the above table. In analyses 3 and 4 it was however necessary to make an adjustment of the percentage of Fe_2O_3 with the FeO which had not been determined separately. The amounts are, however, in any event, so small as not appreciably to affect the diagrams. The pronounced development of the alkalies and alumina below the horizontal line comes out forcibly and furnishes interesting contrasts with the rhyolites.

General Description. — The Phonolite Series embraces a group of rocks not often easy of identification without the microscope. They are rare and are seldom met by the field geologist or engineer. When they are found, however, they afford exceptionally interesting material for detailed study, and, inasmuch as they have been discovered in more recent years in association with some of our most productive gold deposits, they possess an importance for the mining engineer which they formerly lacked. The rocks of the phonolite series are usually dense and finely crystalline; they are very seldom vesicular or even glassy. Dull green and gray are the common colors, but as they approach the trachytes they become lighter in shade. The light-colored minerals are in excess, orthoclase being the most important single component and the only one which is usually large enough to be recognized by the eye alone. The nephelite is almost always too small to be visible without the microscope. Its easy gelatinization, however, makes it possible for the observer often to detect it by simple chemical tests. Thus a small sample of the rock in question is finely powdered and gently warmed in very dilute nitric acid. The nephelite passes readily into solution and when the liquid is decanted from the undissolved grains and is boiled down well toward dryness, gelatinous silica results. No other, common, rock-making and gelatinizing mineral is so easily soluble as nephelite, olivine alone approaching it. The commonest dark silicate in the phonolites is augite and its little dark glistening prisms may occasionally be recognized. Hornblende is very rare, and biotite is almost never seen. All these minerals are only visible when present as phenocrysts; the components of the groundmass cannot be resolved by the eye alone. The fusing point of the phonolites is less than that of the trachytes, being somewhat under 2000° F. (1090° C.).

The *Phonolites proper* are felsitic or slightly porphyritic rocks, which are not always easily to be distinguished from felsitic varieties of trachytes and andesites. They are, however, characteristically dense, and as the rocks often have a peculiar and marked tendency to break up into thin slabs or plates, which ring musically under the hammer, they sometimes reveal themselves in this way. Fig. 18 reproduces a very striking outcrop of phonolite which

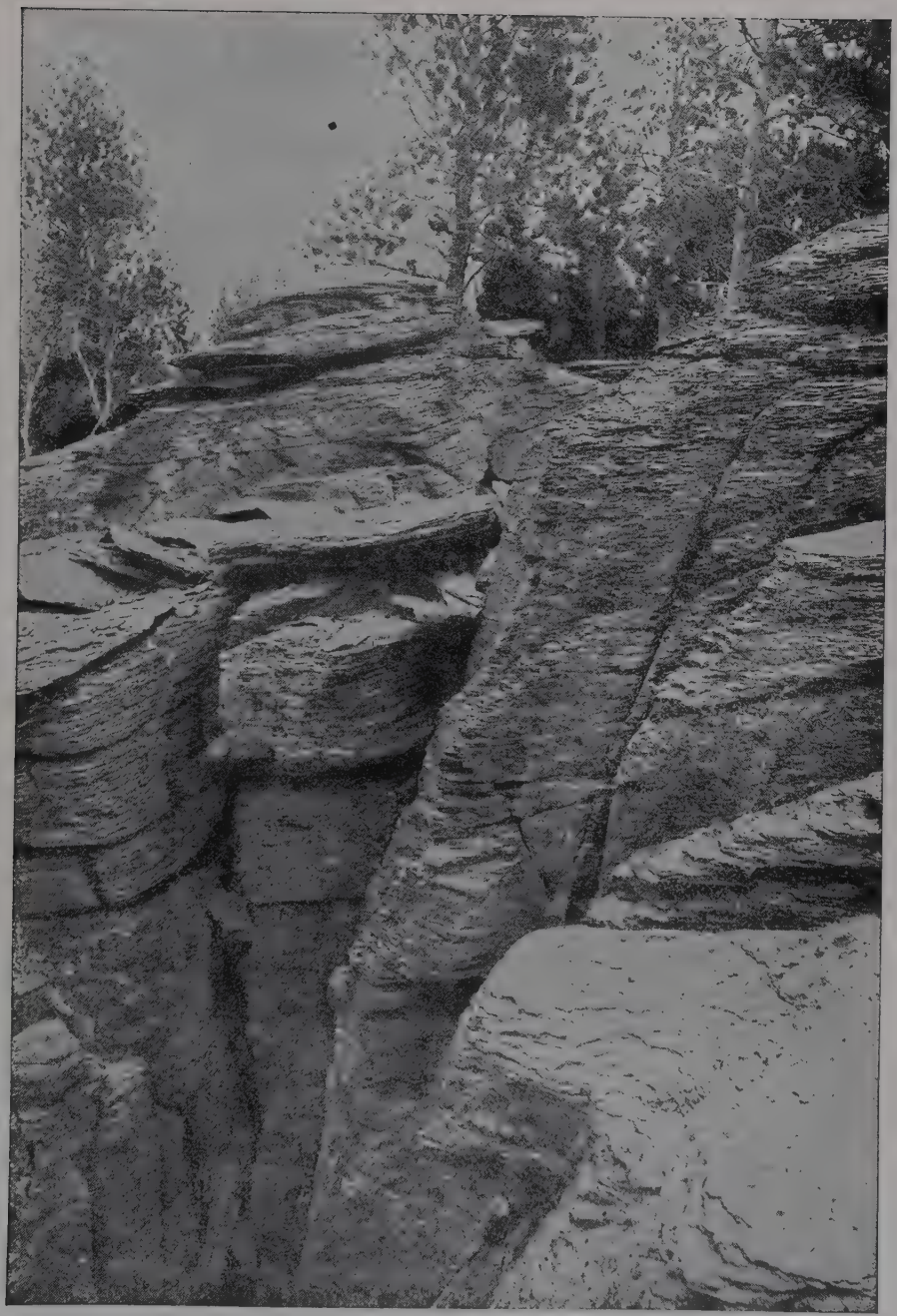


FIG. 18. View of an exposure of platy phonolite, Sugar Loaf Mountain, Black Hills, S. D. J. D. Irving, Annals N. Y. Acad. Sci., XIV., Pl. IX., 1899.

shows this property. The chemical test mentioned above should always be used in corroboration before the identification is positively made. The phonolites proper are found in surface flows and dikes.

The *Phonolite-porphyries* result when the phenocrysts become notably abundant. The phenocrysts are then chiefly orthoclase with a few augites, and perhaps with an occasional titanite. Nephelite in porphyritic crystals is known from a few localities but is seldom seen. The phonolite-porphyries occur in dikes and intruded sheets. When the phenocrysts constitute the greater part of the rock the *Nephelite-syenite porphyries* are developed. They are extremely rare rocks and mark the passage to the nephelite syenites.

Synonyms and Relatives. — The name phonolite is an old one. It was given by Klaproth in 1801 to the rocks which had long been called clinkstone and was merely the Greek equivalent of this colloquial term. Phonolite was formerly restricted to Tertiary and later eruptives but no time distinction is longer implied when it is used, although as a matter of fact most of the known phonolites belong to this portion of geological time. The phonolites are closely related to the trachytes, but they have more soda and alumina and at the same time not enough silica to form albite. Thus as the silica rises there comes a time when albite can absorb all the soda and then nephelite becomes an impossibility. All the more can nephelite never appear with original quartz, because quartz itself is an impossibility until all the albite possible has been produced. The abundant soda in the phonolite magma occasions the frequent production of noselite and hauynite, but they can seldom be detected with the eye alone. For the same reason the dark green, acicular, soda pyroxene ægirite frequently takes the place of the augite and in the groundmass may constitute a perfect felt of little needles. This variety of phonolite is called tinguaite, but it also cannot be readily determined by the unassisted eye. Apachite, gieseckite-porphyry, liebnerite-porphyry, and sussexite are rocks related to the phonolites and will be found defined in the Glossary.

With the increase of orthoclase and the decrease of nephelite the phonolite series passes into the trachytes with which they are in all respects closely akin. With the increase of plagioclase and

the dark silicates they pass in the opposite direction into certain basaltic rocks with nephelite.

The leucite rocks of trachytic affinities constitute a rare and minor group of the phonolite series from which they might with propriety be separated to form a series of their own. They are, however, so rare that they are only mentioned here under the phonolites. When the potash in the magma becomes relatively rich and the silica so poor that there is more than enough of the former and too little of the latter to yield orthoclase, leucite becomes a possibility. Hence it follows that leucite and orthoclase usually go together and that leucite is sometimes found with nephelite, but as soon as the silica becomes abundant enough to combine with all the potash and its attendant alumina, to yield orthoclase, leucite is an impossibility. All the more do we thus never find leucite with original quartz. Felsitic or porphyritic rocks with leucite, orthoclase and augite or some related dark silicate are usually called leucite trachyte. If to this aggregate nephelite be added leucite-phonolite results. The related rocks leucitophyre, orendite and wyomingite will be found defined in the Glossary.

Alterations. — The nephelite changes quite readily to natrolite and perhaps analcite, while leucite yields analcite. Metamorphic processes are yet to be studied.

Distribution. — The true volcanic phonolites are only known in a few localities in this country, such as the Black Hills, where they form dikes, sheets and isolated buttes (Devil's Tower), and the Cripple Creek mining district of Colorado, where the comparatively few dikes known have proved of great importance as associates of the ores. Nephelite- or eleolite-porphyries (tinguaites) are exceedingly rare rocks and have been found near Magnet Cove, Ark., and Beemerville, N. J., associated with nephelite-syenite. Phonolites are much more abundant abroad, being well known in many parts of Germany. The varieties with leucite are especially familiar from the vicinity of Rieden, in the extinct volcanic district of the Eifel. A peculiar leucite rock, with abundant scales of phlogopite, gives the name to the Leucite Hills, two or three miles north of Point of Rocks, Wyo. Leucite tinguaites occur near Magnet Cove, Ark., in the Highwood Mountains, Mont., and near Rio Janeiro, Brazil.

Tuffs are known abroad but not in this country, and exhibit few features calling for special mention.

THE NEPHELITE SYENITES.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	Loss.	Sp. Gr.
1.	60.39	22.51	0.42	2.26	0.32	0.13	4.77	8.44	0.57	
2.	59.70	18.85	4.85	.....	1.34	0.68	5.97	6.29	1.88	
3.	59.01	18.18	1.63	3.65	2.40	1.05	5.34	7.03	0.50	
4.	56.30	24.14	1.99	.....	0.69	0.13	6.79	9.28	1.58	
5.	54.20	21.74	0.46	2.36	1.95	0.52	6.97	8.69		
6.	52.75	22.55	3.65	.....	1.85	0.15	7.05	8.10	3.60	
7.	51.90	22.54	4.03	3.15	3.11	1.97	4.72	8.18	0.22	
8.	50.96	19.67	7.76	.....	4.38	0.36	6.77	7.67	1.38	
9.	50.36	19.34	6.94	.....	3.43	.....	7.17	7.64	3.51	
10.	41.37	16.25	16.93	.....	12.35	4.57	3.98	4.18	0.45	

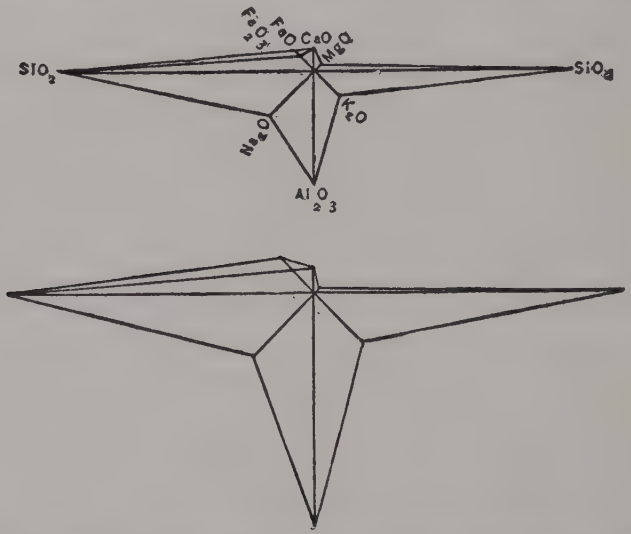
1. So-called Nephelite-syenite, or Litchfieldite, Litchfield, Me., W. S. Bayley, G. S. A., III., 241. 2. Nephelite-syenite, Fourche Mountains, Ark., J. F. Williams, Igneous Rocks of Ark., 88. 3. Nephelite-syenite, Red Mountain, N. H., W. S. Bayley, G. S. A., III., 250. 4. Ditroite, Hungary, Fellner, Neues Jahrb., 1868, 83. 5. Foyaite, Portugal, Jannasch, Neues Jahrb., II., 11. 6. Nephelite-syenite, Sao Paulo, Brazil, Machado, Tsch. Mitt., IX., 1888, 334. 7. Laurdalite, variety of Nephelite-syenite. Lund, Norway, Brögger, Syenit-pegmatit-gänge, 33. 8. Leucite-syenite, Arkansas, J. F. Williams. Igneous Rocks of Ark., 276. 9. Nephelite-syenite, Beemerville, N. J., F. W. Love for J. F. K., N. Y. Acad. Sci., XI., 66. 10. Basic Nephelite-syenite, Beemerville, N. J., J. F. Kemp., N. Y. Acad. Sci., XI., 86.

Comments on the Analyses. — A considerable range is shown in the SiO_2, some analyses going below the usual percentages for syenites and the last analysis being abnormal. In general the amounts of alkalies are extremely high, with Na_2O in excess, in which respect the phonolites are paralleled.

Figs. 19 and 20 are based respectively upon the average molecular ratios and the average percentages of the first seven analyses in the above table. In Nos. 2, 4, and 6 it has been necessary to adjust the undetermined percentages of FeO, but the error, if one is introduced, is not great in any event. The figures closely resemble those of the phonolites and present the same general peculiarities.

Mineralogical Composition and Varieties. — The minerals of nephelite-syenite are in general the same as those of syenite proper, with the addition of nephelite, often sodalite, and several characteristic ones into which the rare earths enter as bases. Zircon is widespread and is often large enough to afford fine crystals.

For this reason the rocks were named zircon-syenite many years ago. The nephelite is often called eleolite (or elæolite), from the former custom of speaking of this mineral in pre-Tertiary rocks as eleolite and in later ones as nephelite, just as we have had orthoclase and sanidine, but the custom is gradually falling into disuse. Attempts have been made to give different names according to the dark silicate; for instance, those with hornblende were called foyaite, from Foya, a Portuguese locality; those with biotite, miascite from Miask, in the Urals. But both these minerals so often appear together or with pyroxene that the practice is not generally observed, Ditroite is a variety rich in blue sodalite. The Litchfield, Maine,



FIGS. 19 AND 20. Diagrams illustrating the chemical composition of the nephelite-syenites which appear in the above table. Fig. 19 is based on molecular ratios; Fig. 20 on percentages.

rock has been shown by Bayley to have as its feldspar albite almost exclusively, and he, therefore, has called it litchfieldite. The texture of nephelite-syenites varies very much. At times it is very coarsely granitoid, and again it is what is called trachytic, *i. e.*, with little rods of feldspar, more or less in flow lines, like a trachyte and marking a passage to the phonolites. Types have been based on these characters. Where at all finely crystalline, the determination of nephelite-syenites, as against true syenites, is a matter for the

microscope. Nephelite-syenites are comparatively rare rocks. Corresponding rocks with leucite are as yet only known from Arkansas and Montana.

Relationships. — As already remarked, the nephelite-syenites are closely related to the true syenites, and to the phonolites. With certain basic plagioclase rocks with nephelite, called theralites, they are also of near kinship.

Geological Occurrence, Alteration. — The nephelite-syenites are specially prone to appear as dikes, often on a very large scale. Their alteration affords no special features, as distinguished from the syenites or granites, except as regards the secondary minerals from the nephelite. Natrolite, muscovite and kaolin are all known in this relation and the last two have been called liebenerite and gieseckite. Cancrinite also results from the alteration of nephelite. The rarity of the nephelite-syenites has prevented their playing an important rôle among metamorphosed rocks.

Distribution. — Nephelite-syenites are known in North America at Montreal and Dungannon, Ont.; Litchfield, Me.; Red Hill, N. H.; Salem, Mass.; Beemerville, N. J., where a superb dike is exposed; near Little Rock, Ark., where the area is extensive; in the San Carlos Mountains, Tamaulipas, Mexico, and at several less well known localities. Very interesting ones occur near Rio Janeiro, and in the State of Sao Paulo, Brazil. Abroad the Portuguese locality, in the Monchique Mountains; the one at Ditro, in Hungary, and the wonderful dikes near Christiania, in Norway, so prolific in rare minerals, are of especial interest.

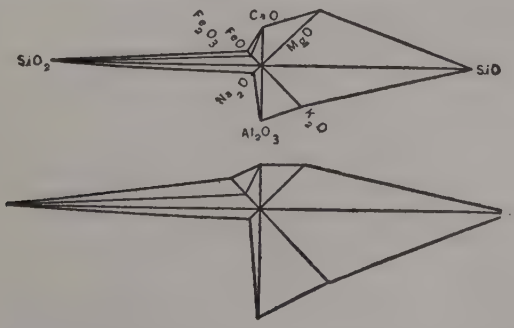


FIG. 21. Diagrams illustrating the chemical composition of Wyomingite, a leucite rock. The upper is based on molecular ratios; the lower on percentages.

The Trachyte-Nephelite-Syenite Table. — The same generalities apply regarding the preparation of this table as are given on p. 38. The recasting brings out several features which might not otherwise be apparent. Thus in the first rock used there is some quartz, but it was not considered sufficient by the original observer to place the rock in the rhyolites. Among the feldspars, orthoclase is sometimes in excess, sometimes albite. Together they constitute from one half to three quarters of the mass. The exception to this relation is the unusual rock shonkinite which is given under 44.7, which is so low in silica as to have almost closer affinities with the basic rocks, such as gabbros, than with the syenites. Anorthite is low in all these rocks. The exigencies of recasting make the use of the nephelite molecule unavoidable. With high Na_2O and low SiO_2 it becomes necessary to infer this relatively basic feldspathoid, even in some trachytes and syenites. As given in the table it may represent some sodalite. Where hydration is marked kaolinite must be assumed. The totals of the light-colored minerals are high. Aside from shonkinite, they range from a maximum of 97.5 to a minimum of 86.5, implying thus a variation of the dark silicates from a minimum of 2.5 to a maximum of 13.5, volumes in every case being used. Under shonkinite however the ratios are changed, there being practically 40 per cent. light-colored as against 60 per cent. dark. Amphiboles or pyroxenes are the chief dark minerals, olivine only appearing in the shonkinite. The proportions of nephelite under the phonolites and nephelite-syenites are of interest in that they show the general amounts of this mineral. We often cannot detect the nephelite without the microscope.

	Trachyte.								Syenite.						Phonolite.				Nephelite-Syenite.					
	40.1*		40.4		40.5		40.6		44.1		44.5		44.7		46.1		46.5		51.3		51.5		51.7	
SiO_2	66.03		62.17		58.70		57.70		60.03		56.45		46.73		61.08		56.43		59.01		54.20		51.90	
Al_2O_3	18.49		18.56		19.26		17.90		20.76		20.08		10.05		18.71		22.25		18.18		21.74		22.54	
Fe_2O_3	2.18		2.15		3.37		4.40		4.01		1.31		3.53		1.91		2.66		1.63		0.46		4.03	
FeO	.22		1.05		.58		3.90		.75		4.39		8.20		.63		.97		3.65		2.36		3.15	
MgO	.39		.73		.76		1.80		.80		.63		9.68		.08		tr.		1.05		.52		1.97	
CaO	.96		1.57		1.41		3.70		2.62		2.14		13.22		1.58		1.41		2.40		1.95		3.11	
Na_2O	5.22		7.56		8.55		3.80		5.96		5.61		1.81		8.68		11.12		7.03		8.69		8.18	
K_2O	5.86		3.88		4.53		7.70		5.48		7.13		3.76		4.63		2.77		5.34		6.97		4.72	
Loss	.85		1.70		2.64		.10		.59		1.77		1.24		2.21		2.05		.50				.22	
Total	100.20		99.30		99.8		101.00		101.00		99.51		98.22		99.51		99.66		98.79		96.89		99.82	
	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt	Vol	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.
Quartz	8.4	8.2																						
Orthoclase †	35.1	35.6	22.8	21.3	26.7	26.8	45.6	48.3	32.8	33.6	41.7	42.6	22.2	26.6	27.2	27.5	16.7	16.8	31.7	33.7	41.1	44.0	27.8	30.0
Albite	44.0	44.0	55.2	56.5	43.0	42.4	23.3	24.3	43.6	43.9	22.5	22.5			52.4	51.8	46.6	46.3	39.0	40.7	13.1	13.7	18.3	19.3
Anorthite	4.7	4.4	7.8	7.5	4.5	4.1	8.9	8.7	13.1	12.3	8.9	8.4					3.6	3.3	2.2	1.6			10.8	10.1
Nephelite			1.1	1.1	12.2	12.0	4.7	4.9	3.6	3.5	13.4	13.3	8.2	9.5	8.7	8.7	24.4	24.0	10.9	11.3	32.7	34.0	27.6	29.0
Kaolinite	4.4	4.7	1.0	1.1					.5	.6														
Amphibole	.26	2.1							4.2	3.5														
Pyroxene			10.2	8.3	8.9	6.9	12.0	10.1			9.3	7.6	47.4	45.2	6.6	5.4	3.4	2.7	11.9	10.1	9.3	7.9	9.1	7.8
Olivine													13.9	11.8										
Magnetite	.7	.4			1.9	1.0	6.3	3.4	2.6	1.3	1.9	1.0	5.1	3.1	1.4	.9	3.0	1.6	2.3	1.3	.7	.4	5.8	3.2
Water	.2	.6	1.6	4.2	2.6	6.8	.1	.3	.5	1.3	1.8	4.6	1.2	3.8	2.2	5.7	2.0	5.3	.5	1.3			.2	.6
Total	100.1	100.0	99.7	100.0	99.8	100.0	100.9	100.0	100.9	100.0	99.5	100.0	98.0	100.	98.5	100.	99.7	100.0	98.5	100.0	96.9	100.0	99.6	100.0
Light-colored Minerals	96.8	97.5	89.5	91.7	89.0	92.1	82.6	86.5	94.1	95.2	88.3	91.4	31.6	39.9	90.5	93.7	93.3	95.7	84.3	88.6	86.9	91.7	84.7	89.0
Dark-colored Minerals	3.3	2.5	10.2	8.3	10.8	7.9	18.3	13.5	6.8	4.8	11.2	8.6	66.4	60.1	8.0	6.3	6.4	4.3	14.2	11.4	10.0	8.3	14.9	11.0

* The double numbers refer to the page and the analysis, where earlier given.

† All the K_2O has been calculated as orthoclase. There may be at times a little biotite.

CHAPTER IV.

The Igneous Rocks, Continued. The Dacite-Quartz-diorite Series and the Andesite-Diorite Series.

THE DACITE–QUARTZ–DIORITE SERIES.

The Dacites.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	Loss.	Sp. Gr.
1.	69.96	15.79	2.50	...	1.73	0.64	3.80	4.12	1.53	
2.	69.36	16.23	0.88	1.53	3.17	1.34	4.06	3.02	0.45	
3.	67.49	16.18	1.30	1.22	2.68	1.34	4.37	2.40	2.69	
4.	67.2	17.0	3.5	1.2	4.5	1.5	3.7	1.6	0.9	
5.	67.03	16.27	...	3.97	3.42	1.19	2.71	3.50	1.56	
6.	66.03	14.57	2.57	1.19	3.38	1.89	3.71	2.70	2.07	
7.	63.36	16.35	2.12	3.05	4.79	3.28	3.58	2.92	0.99	

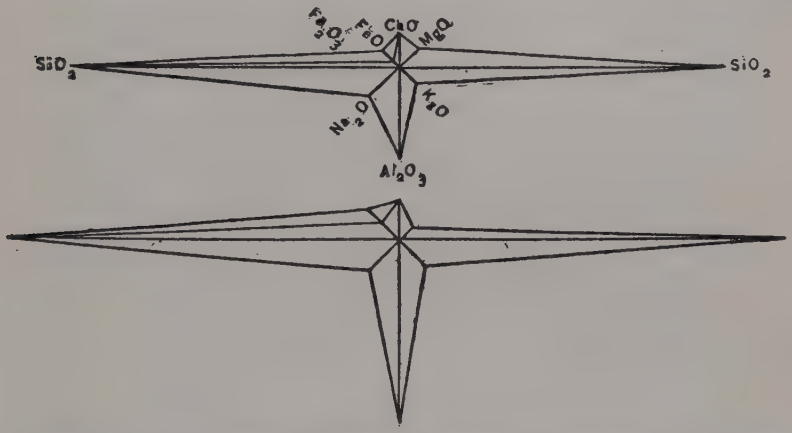
1. McClelland Peak, near Comstock Lode, Nev., F. A. Gooch, Bull. 17, U. S. G. S., 33. 2. Lassen's Peak, California, Hague and Iddings, A. J. S., Sept., 1883, 232. 3. Sepulchre Mountain, Yellowstone Park, J. P. Iddings, Phil. Soc. Wash., XI., 210. 4. Nagy-Sebes, Hungary, Doelter, Tscher. Min. Petr. Mitt., 1873, 93. 5. Eureka Dist., Nev. A. Hague, Mono. XX., U. S. G. S., 264. 6–7. Colombia, S. America, From Küch's Petrographie of Colombian Volcanoes, quoted in Jour. Geol., I., 171.

Comments on the Analyses. — It appears at once from the analyses that the dacites are high in silica, in which they equal the lower ranges of rhyolites. As compared with the latter, soda is prevailingly in excess of potash, and as a rule the other bases run higher and especially the lime.

The diagrams in Figs. 22 and 23, show considerable similarity with those of the rhyolites, but on close comparison it will appear that in the former, the soda is in marked excess over the potash and both the lime and the magnesia are represented by longer intercepts.

General Description. — The Dacites embrace a group of rocks which so strongly resemble the rhyolites as often to make it difficult, if not impossible, for an observer to positively identify them as against the latter. The light-colored minerals are the ones which give character to the group. Quartz and feldspar are the prominent components and the prevailing feldspar is plagioclase, and one of the more acidic varieties. Biotite is perhaps the most

common of the dark silicates but both hornblende and augite are frequent. The minor accessories, apatite, zircon, magnetite, etc., are seldom visible to the eye. The prevailing colors are light



FIGS. 22 AND 23. Diagrams illustrating the chemical composition of the dacites which are given in the above analyses. Fig. 22 is based on molecular ratios; Fig. 23 on percentages.

grays, yellows and pale reds. The fusing point is perhaps slightly less than that of the rhyolites. Glasses and cellular textures are not uncommon.

The textures of the dacites range from felsitic to coarsely porphyritic. The *Dacites proper* are felsitic to moderately porphyritic rocks, sometimes cellular from their crystallization as surface flows. When finely felsitic their components cannot be distinguished and recognized with the eye alone, and then the microscope is the sole resource for accurate determination. They can otherwise only be called felsites. When, however, the phenocrysts become prominent the only possible question is between dacites and rhyolites, for these are the only two with quartz in this relation. The observer must then study the cleavage faces of the feldspars with a good lense, and if the greater number of these display the striations peculiar to plagioclase the identification of the dacites can be satisfactorily made.

When the phenocrysts become abundant the dacites proper pass into the *Dacite-porphyries*. The groundmass is, as a rule, felsitic. The cellular texture disappears entirely and the rocks become dense and characteristically porphyritic types. The interiors of

thick surface flows, the dikes, intrusive sheets and the outer parts of laccoliths are their special homes.

When phenocrysts are in marked excess over the groundmass and constitute the greater part of the rock, the *Quartz-diorite porphyries* result. The groundmass is rather coarsely felsitic and becomes increasingly coarse as the quartz diorites are approached. All the minerals forming the phenocrysts are now not difficult to recognize. The quartz-diorite porphyries are met in deep-seated dikes, thick intrusive sheets, and in the central parts of laccoliths. They mark a textural transition to the quartz diorites.

Synonyms and Relatives. — The name dacite was created in 1863 by an Austrian geologist, G. Stache, who had been working upon the eruptives of the old Roman province of Dacia, now in the district of Hungary known as the Siebenbürgen. Under it was embraced a series of rocks somewhat indefinitely called by earlier lithologists andesitic quartz-trachytes, and other undesirable names. The name dacite has proved to be a useful one and is quite universally employed to-day. The dacites were originally considered to be necessarily Tertiary or later in geological age but now no time restriction is applied to them. Varieties are sometimes made on the basis of the dark silicate present such as mica-dacite, hornblende-dacite or augite-dacite. The dacites are close relatives of the andesites into which they pass with increasing basicity, and with the disappearance of quartz. They are also very closely akin to the rhyolites and to those passage rocks from rhyolites to dacites, called pantellerites and keratophyres, which are defined in the Glossary. Quartz-porphyrite is an old synonym of dacite porphyry.

Alteration, Metamorphism. — The alteration of the dacites is practically like that of the rhyolites, but the greater abundance of soda-lime feldspar may yield a trifle more calcite. The light-colored silicates change to kaolin. In metamorphism the dacites yield siliceous schists especially when greatly mashed or sheared.

Tuffs. — The tuffs and breccias are essentially like those of the rhyolites. From them on account of the almost universal advance of alteration they cannot readily be distinguished without the microscope and even then the sharp determination may present great difficulties.

Distribution. — Dacites usually appear as subordinate members in eruptive regions where the andesites are the chief rocks. They are therefore widespread in the volcanic districts of the Cordilleran region and of Central and South America.

THE QUARTZ-DIORITES.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	Loss.
1.	70.36	15.47	0.98	1.17	3.18	0.87	4.91	1.71	1.06
2.	67.54	17.02	2.97	0.34	2.94	1.51	4.62	2.28	0.55
3.	65.27	15.76	1.36	3.44	3.70	2.14	4.57	3.97	0.42
4.	63.97	15.78	2.35	1.87	3.71	2.84	4.36	4.01	0.58
5.	62.43	17.88	1.78	3.53	3.43	4.50	3.10	2.75	1.37

1. Quartz-diorite, Enterprise, Butte Co., Calif., H. W. Turner, Anals. by W. F. Hillebrand, 14 Ann. Rep. U. S. Geol. Survey, 482, 1894. 2. Quartz-mica-diorite, Electric Peak, Yellowstone Park, J. P. Iddings, Anal. by Whitefield, Bull. Phil. Soc. of Washington, II., 206. 3. Quartz-augite-diorite, Watab, Minn., A. Streng, Neues Jahrbuch, 1877, 232. 4. Quartz-mica-diorite, Crandall Basin, Wyo., J. P. Iddings, Mono. 32, U. S. G. S., p. 261, W. H. Melville, Analyst. 5. Quartz-mica-diorite, Omeo, Vict., A. W. Howitt, Trans. Roy. Soc. Vict., XXII., 99.

Comments on the Analyses. — The quartz-diorites, although acidic rocks, do not have as high percentages of silica as the granites, but in lime and soda they range slightly higher on account of the prevailing plagioclase. In general they strongly resemble the granites and diagrams based on the above analyses would hardly differ from those of the granites given earlier.

Mineralogical Composition, Varieties. — The quartz-diorites are granitoid rocks whose chief feldspar is plagioclase and which contain also quartz as an essential component. The dark silicates are hornblende and biotite, one or both. The light-colored minerals are in excess over the dark ones, but this relationship is less pronounced in the more basic varieties. The typical mineralogical aggregate contains hornblende. When biotite is the chief, dark silicate the rocks are called quartz-mica-diorites. The fusing point of the rocks is a shade less than that of the granites.

From all other rocks except granites the quartz-diorites are distinguished by their granitoid texture and quartz. From the granites the prevalence of striated feldspar is the chief distinction.

Relationships. — The quartz-diorites are close relatives of the granites on the one hand and of the diorites on the other. To the former group an easy transition is afforded by the grano-

diorites, while the so-called quartz-monzonites mark a transition to the syenites. Tonalite and adamellite will be found defined in the Glossary.

Geological Occurrence. — The quartz-diorites form batholiths, dikes and local developments of diorites.

Alteration. — The alteration is in all essentials similar to that of granite.

Distribution. — Quartz-diorites occasionally appear in the eastern areas of crystalline rocks. A famous one with mica is an important member of the Cortlandt series of eruptives near Peekskill, N. Y. Others with hornblende are known in the Yellowstone Park and in the Sierras.

THE ANDESITE–DIORITE SERIES.

The Andesites.

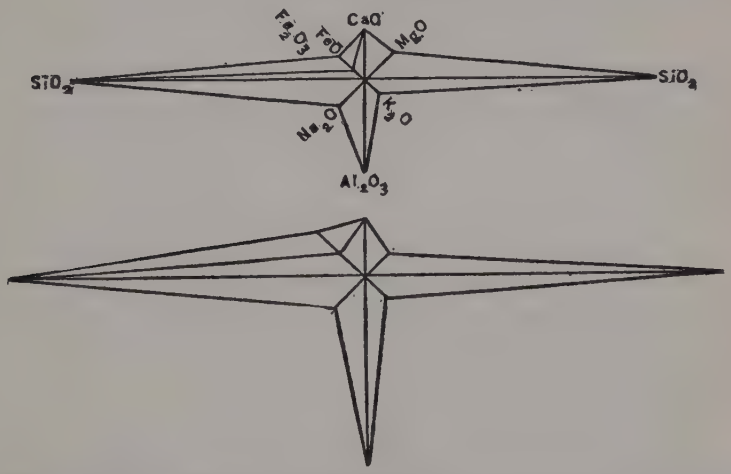
	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	Loss
1.	67.83	15.02	...	5.16	3.07	0.29	2.40	3.20	1.11
2.	65.50	14.94	1.72	2.27	2.33	2.97	5.46	2.76	1.37
3.	63.49	18.40	2.44	1.09	2.30	0.66	5.70	4.62	1.04
4.	62.94	18.14	...	3.82	6.28	3.06	3.83	1.22	0.60
5.	61.62	16.86	...	6.61	6.57	2.07	3.93	1.66	
6.	61.58	16.34	...	6.42	5.13	2.85	2.69	3.65	0.64
7.	59.48	16.37	3.21	3.17	4.88	3.29	3.30	2.81	2.02
8.	56.19	16.12	4.92	4.43	6.99	4.60	2.96	2.37	1.03
9.	56.91	18.18	4.65	3.61	7.11	3.49	4.02	1.61	0.36

1. Hb.-mica-andesite, Eureka Dist., Nev., Mono. XX., U. S. G. S., 264. 2. Hb.-mica-andesite, Sepulchre Mountain, Yellowstone Park, J. P. Iddings, Phil. Soc. Wash., XI, 210. 3. Mica-andesite, Rosita Hills, Colo., W. Cross, Colo. Sci. Soc., 1887, 250. 4. Lassen's Peak, Calif., Hague and Iddings, A. J. S., Sept., 1883, 225. 5. Mt. Rainier. See last reference. 6. Pyroxene-andesite, Eureka Dist., Nev., Mono. XX., U. S. G. S., 264. 7. Hypersthene-andesite, near Red Bluff, Mont., G. P. Merrill, Proc. U. S. Nat'l Museum, XVII., 651. 8. Hypersthene-andesite, Buffalo Peaks, Colo., W. Cross, Bull. I., U. S. G. S., 26. 9. Colombia, S. America.

Comments on the Analyses.—It appears at once from the analyses that the andesites lap over the lower limits of the dacites and have much the same range in silica as the trachytes. All the bases reach notable percentages, but the alkalies recede as the others increase.

As compared with both dacites and trachytes these contrasts are well brought out in the diagrams, Figs. 24 and 25. The intercepts of silica shorten, whereas those of lime and magnesia notably lengthen.

General Description. — The Andesite series embraces a large and wide-spread group of rocks, which marks an important step from the more acidic to the more basic limits of the igneous types. Its members are emphatically rocks of medium acidity, with the light-colored minerals still in excess over the dark-colored ones. The feldspars are therefore the most prominent components but there is a marked increase in the ferromagnesian silicates as compared with the dacites. Quartz fails except as a rare and sporadic component. Hornblende and augite begin to take precedence over



FIGS. 24 AND 25. Diagrams illustrating the chemical composition of the andesites, based on the above analyses. Fig. 24 refers to molecular ratios; Fig. 25 to percentages.

biotite, but all three are common. The prevailing colors are grays or greens, mottled by the light and dark phenocrysts. The andesites have fusing points near 2000° F. (1100° C.). They rarely afford large amounts of glasses.

The textures of the Andesite series range from felsitic to coarsely porphyritic. The *Andesites proper* are felsitic or moderately porphyritic rocks, sometimes cellular from their crystallization as surface flows. When finely felsitic they cannot be readily distinguished from the trachytes and even from the dacites and rhyolites of the same texture, although they are usually provided with more of the dark silicates than are the last two. For sharp determination recourse must be had to the microscope, but it is fair to men-

tion that andesites are much more abundant rocks in Nature than are trachytes, so that in doubtful cases the chances strongly favor the former. When examined with the microscope the finely crystalline groundmasses of the andesites are often found to be a fine felt of little rods of feldspar, giving a texture that is fairly characteristic of this group.

With the development of phenocrysts the exact determination of the andesites becomes less difficult. Quartz fails and the feldspars constitute the more prominent porphyritic crystals. The cleavage faces of the latter should then be examined with a lense and if the greater number exhibit the characteristic striations of plagioclase the andesites may be recognized as against the trachytes. This determination may be further fortified by the frequent greater prominence of the dark silicates. The andesites proper occur characteristically in surface flows.

As the phenocrysts become abundant the andesites proper pass into the *Andesite-porphyries.* The groundmass is, as a rule, felsitic. The cellular texture disappears entirely and the rocks are dense and markedly porphyritic. The interiors of thick surface flows, the dikes and intrusive sheets and the outer parts of laccoliths are their special home.

When phenocrysts are in marked excess over the groundmass and constitute the greater part of the rock the *Diorite-porphyries* result. The groundmass is rather coarsely felsitic and becomes increasingly so as the diorites are approached. All the minerals forming the phenocrysts are now not difficult to recognize. The diorite-porphyries occur in deep-seated dikes, thick intrusive sheets and the central parts of laccoliths. They mark a textural transition to the diorites.

Synonyms and Relatives. — The name andesite was first proposed by L. von Buch in 1835 for certain lavas from the Andes Mountains which consisted of albite and hornblende, and which therefore differed from trachyte in the old sense. The name did not come into general use until 1858 since which time it has been quite universally employed for the porphyritic and felsitic plagioclase-bearing eruptives of medium acidity. For a time it was restricted to the Tertiary and later rocks but this limitation is no longer current and textural features are alone emphasized. Ande-

sites whose chief dark silicate is biotite are called mica-andesites; those with hornblende, hornblende- or amphibole-andesites; while those with augite are known as augite-andesites. Hypersthene-andesites are occasionally met and result when the magma is rich in magnesia. The augite-andesites differ from the olivine-free basalts in having the light-colored minerals in excess.

While the time-distinction was still preserved in the classification of igneous rocks, the pre-Tertiary andesites were called by some porphyrite, to which name the several prefixes, mica, hornblende and augite were attached. Later porphyrite was employed for the deep-seated or intrusive andesites, which are here called andesite-porphyry and diorite-porphyry, but even this use is practically obsolete as it is certainly unnecessary. Other rock-names more or less closely related to andesite, such as asperite, propylite, volcanite and latite will be found defined in the Glossary.

Andesites, with the increase of orthoclase and the corresponding decrease of plagioclase, pass into the trachytes; and with the increase of the dark silicates and corresponding decrease of feldspar they shade into the basalts. The appearance of quartz in notable amounts marks a transition to the dacites. Practically unbroken series can easily be selected to all these related groups.

Alteration, Metamorphism. — The andesites in decay afford kaolinized material and mixtures of this with chloritic products that are very difficult to identify. Thus the now famous andesitic breccia at Cripple Creek, Colo., can rarely be shown to the eye to be other than a white, kaolinized mass, and decomposed outcrops of massive flows are no less unsatisfactory. Where metamorphic processes affect older flows, felsitic and silicified forms result similar to those mentioned under rhyolites. The tracing of the history of the rock is then a matter for the microscope and chemical analysis when indeed it can be done.

Tuffs. — Andesitic tuffs and breccias (*i. e.*, aggregates of angular, volcanic ejectments coarser than tuffs) are rather common in the western volcanic districts. With ordinary observation they can only be identified by finding fragments large and fresh enough to indicate the original. Such have proved of great economic importance at Cripple Creek, Colorado.

Distribution. — Andesites are very wide-spread in the West. The vast laccoliths that form many of the peaks in Colorado are intruded andesite-porphyries of a rather acidic type, frequently with some orthoclase. In the Yellowstone Park they are important. In Nevada, as at Eureka and the Comstock lode, they have proved of great geological interest, and especially in and near the latter, with its many miles of drifts, shafts and tunnels, very important data for the study of rock masses have been afforded. The old cones along the Pacific, Mt. Hood, Mt. Shasta, Mt. Rainier and others are chiefly andesite. The products of Mexican and South American volcanoes are also of this type, and indeed along the whole Pacific border the recent lavas have many features in common. Abroad andesites are seldom lacking in great volcanic districts.

THE DIORITES.

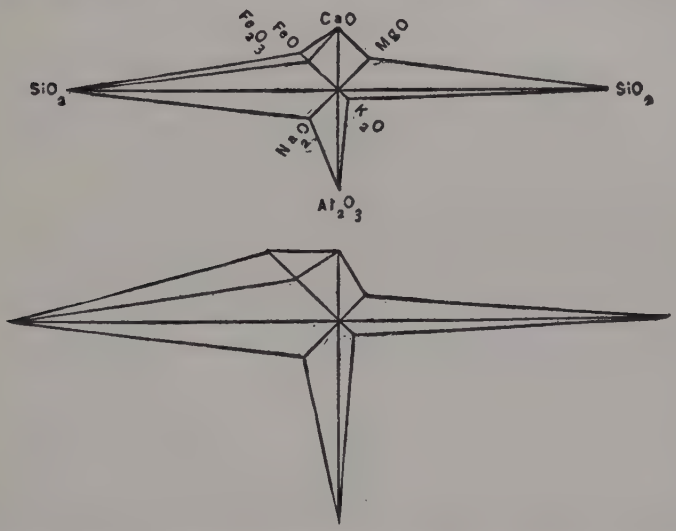
	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	Loss.	Sp. Gr.
1.	61.75	18.88	0.52	3.52	3.54	1.90	3.67	1.24	4.46	2.79
2.	58.05	18.00	2.49	4.56	6.17	3.55	3.64	2.18	0.86	
3.	56.71	18.36	...	6.45	6.11	3.92	3.52	2.38	...	2.86
4.	52.35	15.72	2.90	7.32	8.98	7.36	2.81	1.32	1.35	
5.	50.47	18.73	4.19	4.92	8.82	3.48	4.62	3.56	0.58	2.87
6.	48.98	17.76	2.14	6.52	8.36	2.09	6.77	2.08	4.50	
7.	48.19	16.79	18.37	...	6.85	1.32	5.59	1.11	2.31	

1. Diorite. Pen-maen-mawr, Wales, J. A. Phillips, Q. J. G. S., XXXIII., 424, 1877. 2. Diorite, Electric Peak, Yellowstone Park, J. P. Iddings, Bull. Phil. Soc. Washington, II., 206. 3. Diorite (granitoid andesite?), Comstock Lode, Nev., R. W. Woodward, 40th Par. Survey, I., opp. p. 676. 4. Augite-diorite, Little Falls, Minn., A. Streng, Neues Jahrb., 1877, 129. 5. Augite-diorite, Mt. Fairview, Custer Co., Colo., W. Cross, Anal. by Eakins, Col. Sci. Soc., 1887, 247. 6. Porphyritic-diorite, St. John, N. B., W. D. Matthew, Trans. N. Y. Acad. Sci., XIV., 213. 7. Diorite dike rich in magnetite, Forest of Dean Mine, N. Y., J. F. Kemp, A. J. S., Apr., 1888, 331.

Comments on the Analyses. — As regards silica the analyses begin where those of the quartz-diorites leave off, and extend to lower limits than those of the andesites. The last three are indeed more basic than is typical of the diorites. The bases, iron, lime and magnesia show a marked increase, but in the typical cases do not yet reach the figures of the basaltic rocks which follow. Soda is in excess over potash as would follow from the prevalence of plagioclase.

Figs. 26 and 27 are of special interest when compared with those of the andesites which they greatly resemble. The diorites

show a slight increase in the intercepts above the horizontal, a slight decrease in silica and in potash, but in other respects they are, as they ought to be, very much the same as Figs. 24 and 25.



FIGS. 26 AND 27. — Diagrams illustrating the chemical composition of the diorites, which are given in the above analyses. Fig. 26 is based on molecular ratios; Fig. 27 on percentages.

Mineralogical Composition. — The diorites are granitoid igneous rocks, whose chief feldspar is plagioclase and whose chief dark silicate is either hornblende or biotite. Those with hornblende are called simply diorites; those with biotite, mica-diorites. Some augite is often present, marking a passage to the gabbros and giving the rock the name augite-diorite. It is however a matter of much difficulty to distinguish hornblende from augite with the eye alone, and unless the observer can make certain of the cleavages — approximately 120° for hornblende, and 90° for augite — doubt may arise. In the typical diorites the feldspars are in excess over the dark silicates and contrasts are thus afforded with the typical gabbros, but the name diorite in ordinary use is often applied to rocks with a decided excess of hornblende. Additional difficulty in the sharp application of the word arises because under the influence of metamorphism original augite, as for instance in a gabbro, changes readily in whole or in part to hornblende, and a mineral-

ogical aggregate thus results which corresponds to diorite, yet which did not crystallize directly in this form. When working with the microscope the observer can follow out these changes, but when depending on the eye alone, it is necessary to base the determination on the minerals as we find them.

Magnetite, titanite and apatite are almost always present as accessory minerals in the diorites, but are usually too small to be seen. Garnet is not infrequent, and pyrrhotite at times is in considerable amount.

The name diorite was first applied in 1822 by the Abbé Haüy. It is derived from the Greek verb, to distinguish, and was suggested by the fact that in the rocks first named the white feldspar could be easily distinguished from the black hornblende. In the course of time it became a very widely used field name among geologists and miners.

As noted in the definition of diorite in the Glossary there is a decided disposition among students of rocks, especially when working with the microscope, to apply the name diorite to those varieties of the plagioclase rocks whose feldspar is more acidic than labradorite; that is when the plagioclase comes within the albite-andesine ranges. The dark silicate may then be hornblende, biotite or pyroxene. The rocks with the more basic plagioclases are classed with the gabbros. Without the microscope, these distinctions among the plagioclases are, however, impracticable.

Varieties. — The varieties mica-diorite and augite-diorite have already been defined. A dioritic rock occurring in dikes and containing both hornblende and biotite has been named kersantite. Camptonite is applied to a rock, found in dikes which are often met in close association with nephelite-syenite and which have the composition of hornblende-diorite. Additional details regarding both these as well as augite-diorite and definitions of banatite, vogesite, and kersanton will be found in the Glossary.

Alteration, Metamorphism.—In ordinary alteration the feldspar of diorites kaolinizes and the hornblende changes to chlorite, affording one of the varieties of the so-called greenstones. Under shearing stresses in metamorphism the diorites pass into gneisses, and into hornblende schists or amphibolites. In many mining regions even

decidedly schistose varieties are still called diorite. A final stage is chlorite-schist, wherein the hornblende has altered to chlorite.

Distribution.—True, original diorites are not very common rocks in America. In the Sudbury nickel district, north of Lake Huron, dense, dark diorites are the chief rock containing the ore, but there is always the possibility that the hornblende is altered augite. Mt. Davidson, above the Comstock Lode, is either a true diorite or a granitoid phase of andesite. Authorities differ as to its interpretation.

Diorites are well known abroad and have been described from various places in Great Britain, Germany, France and Austria.

The Dacite-Diorite Table. — Regarding the recasting of these analyses the general remarks given on p. 38 also apply. With the increase of the dark silcates additional difficulties arise in that the Al_2O_3 is not so largely limited to the feldspars. The chief chemical difference as compared with the rocks already discussed is the increase in the CaO. It brings about the great advance in the anorthite and contributes to the amphibole. Under amphibole some pyroxene may also be understood as possible. It is interesting to note that quartz must be assumed in all the analyses of andesites, although in most of them the silica appears scarcely to suggest it. Orthoclase appears in every analysis. With one exception (64.4) albite is the most abundant molecule. Anorthite ranges from a minimum of 7.7 to a maximum of 27, high values compared to the rocks already passed in review. The light-colored minerals vary in total from a maximum of 96 to a minimum of 65.2, always using volumes. The dark-colored ones range from 4 to 34.8. They are chiefly amphibole, sometimes with biotite, olivine and pyroxene, which last was not specially calculated. Magnetite is always in evidence and reaches abnormal values in the last analysis, which was made of a dike, where it cut a large ore-body of magnetite.

	Dacite.						Quartz–Diorite.						Andesite.						Diorite.					
	56.2*		56.6		56.7		5.91		59.3		59.5		60.2		60.7		60.8		64.2		64.4		64.7	
SiO_2	69.36		66.03		63.36		70.36		65.27		62.43		65.50		59.48		56.19		58.05		52.35		48.19	
Al_2O_3	16.23		14.57		16.35		15.47		15.76		17.88		14.94		16.37		16.12		18.00		15.72		16.79	
Fe_2O_3	.88		2.57		2.12		.98		1.36		1.78		1.72		3.21		4.92		2.49		2.90		18.37	
FeO	1.53		1.19		3.05		1.17		3.44		3.53		2.27		3.17		4.43		4.56		7.32		n.d.	
MgO	1.34		1.89		3.28		3.87		2.14		4.50		2.97		3.29		4.60		3.55		7.36		1.32	
CaO	3.17		3.38		4.79		4.18		3.70		3.43		2.33		4.88		6.99		6.17		8.98		6.85	
Na_2O	4.06		3.71		3.58		1.91		4.57		3.10		5.46		3.30		2.96		3.64		2.81		5.59	
K_2O	3.02		2.70		2.92		1.71		3.97		2.75		2.76		2.81		2.37		2.18		1.32		1.11	
Loss	.45		2.07		.99		.06		.42		1.37		1.37		2.02		1.03		.86		1.35		2.31	
Total	100.04		98.11		100.44		99.71		100.63		100.77		99.32		98.53		99.61		99.50		100.11		100.53	
	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.
Quartz	27.0	27.3	24.6	24.7	15.2	15.3	26.9	26.4	11.4	11.5	17.7	18.0	13.6	13.5	13.3	13.5	8.9	9.4	8.4	8.7				
Orthoclase	14.5	15.4	16.1	16.8	17.2	18.1	10.0	10.4	23.3	24.7	16.1	17.0	16.1	16.7	16.7	17.1	13.3	14.7	12.8	13.8	7.8	8.6	6.7	7.5
Albite	34.1	35.0	30.9	31.7	30.4	31.5	41.4	41.8	38.3	39.5	26.2	27.0	46.1	47.7	27.8	29.0	25.2	27.3	30.4	32.2	23.6	25.6	47.2	51.4
Anorthite	15.6	15.3	15.3	14.7	19.8	19.2	15.3	14.4	11.1	10.8	17.0	16.4	8.1	7.7	21.7	21.2	23.9	24.2	26.4	26.3	26.4	27.0	10.0	10.3
Biotite	7.3	6.8																						
Amphibole			5.4	4.5	13.8	11.6	3.7	3.0	13.6	11.4	19.8	16.5	11.5	9.5	12.4	10.8	20.1	17.7	16.9	14.6	36.1	32.0	16.0	14.2
Olivine																					.6	.5		
Magnetite	1.6	0.1	3.7	2.0	3.0	1.6	1.9	1.0	1.9	1.0	2.6	1.4	2.3	1.2	4.6	2.4	7.0	3.9	3 5	2.0	4.0	2.3	17.8	10.1
Water	.3	0.1	2.1	5.6	1.0	2.7	1.1	3.0	.4	1.1	1.4	3.7	1.4	3.7	2.0	5.4	1.0	2.8	.9	2.4	1.4	4.0	2.3	6.5
Total	100.4	100.0	98.1	100.0	100.4	100.0	100.3	100.0	100.0	100.0	100.8	100.0	99.1	100.0	98.5	100.0	99.4	100.0	99.3	100.0	99.9	100.0	100.0	100.0
Light-Colored Minerals	91.5	93.1	89.0	93.5	83.6	86.8	94.7	96.0	84.5	87.6	78.4	82.1	85.3	89.3	81.5	86.8	72.3	78.4	78.9	83.4	59.2	65.2	66.2	75.6
Dark-colored Minerals	8.9	6.9	9.1	6.5	16.8	13.2	5.6	4.0	15.5	12.4	22.4	17.9	13.8	10.7	17.0	13.2	27.1	21.6	20.4	16.6	40.7	34.8	33.8	24.3

*The double numbers refer to the page and the analysis, where earlier recorded.

CHAPTER V.

The Igneous Rocks, Continued. The Basalt-Gabbro Series. The Feldspar-free Basalts. The Pyroxenites and Peridotites. The Ultra-Basic Rocks.

THE BASALT–GABBRO SERIES.

The Basalts.

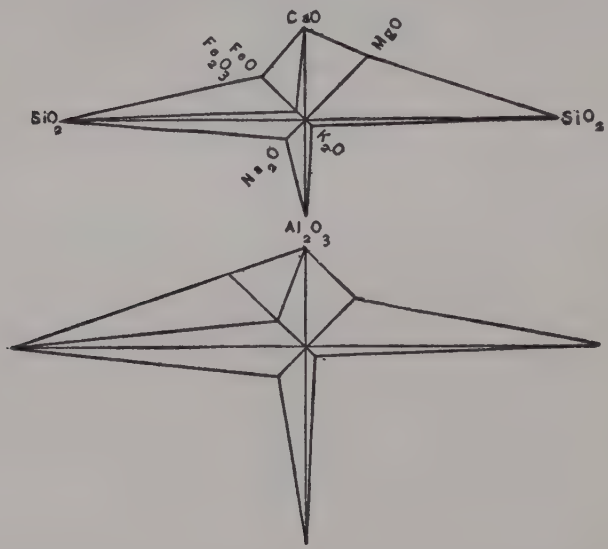
Basalts.	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	Loss.	Sp. Gr.
1.	57.25	16.45	1.67	1.77	7.65	6.74	3.00	1.57	0.45	
2.	53.81	13.48	3.02	7.39	10.34	6.46	3.23	0.64	0.57	2.75
3.	53.62	22.09	4.21	....	6.02	6.24	3.16	0.57	5.03	
4.	52.27	17.68	2.51	5.00	8.39	6.05	4.19	1.58	0.82	
5.	51.58	11.92	2.96	13.05	8.52	4.09	0.95	0.34	1.52	2.989
6.	50.38	19.83	6.05	2.00	10.03	5.36	2.15	1.76	1.37	
7.	49.45	17.58	3.41	3.41	7.20	4.05	5.83	1.57	4.34	
8.	49.04	18.11	2.71	7.70	7.11	4.72	4.22	2.11	1.29	2.738
9.	48.40	17.95	2.28	8.85	10.05	6.99	2.86	1.03	0.34	2.8
10.	47.54	19.52	4.24	6.95	11.70	6.66	3.09	0.16		2.981
11.	46.43	17.10	11.16	...	10.38	9.78	2.50	...	2.65	

1. Basalt with quartz, Cinder Cone, Calif., J. S. Diller, A. J. S., Jan., 1887, p. 49, Anal. Hillebrand. 2. Kilauea, Sandwich Is.; Cohen., Neues Jahrb., 1880, II., 41. 3. Iceland, Schirlitz, Tsch. Mitth., 1882, 440. 4. Rio Grande Cañon, N. M., J. P. Iddings, A. J. S., Sept., 1888, 220, Anal. Eakins. 5. Dalles, Oregon, Lemberg, Z. d. d. g. G., XXXV., 116. 6. Richmond Mtn., Eureka Dist., Nev., A. Hague, Mono. XX., U. S. G. S., 264, Anal. Whitfield. 7. Point Bonita, Calif., F. L. Ransome, Bull. Geol. Dept. Univ. Calif., I., 106. 8. Buffalo Peaks, North Park, Colo., Woodward, 40th Parallel Surv., II., 126. 9. Shoshone Mesa, Nev., Woodward, 40th Par. Surv., II., 617. 10. Cascade Mts., Oregon, Jannasch, Tsch. Mitth., 1881, 102. 11. Glassy basalt, Edgecombe Island, near Sitka, Alaska, Lemberg, Z. d. d. g. G., XXXV., 570.

Comments. — The first analysis is very like the more basic andesites, except in its high percentage of MgO. It is of a curious and exceptional basalt with quartz phenocrysts, regarding which mention is made later. In general, the others are notably high in the oxides of iron, in CaO and MgO. The alkalies wane because of the increasing inferiority of the feldspars, which give place to augite and olivine. The specific gravity is high.

The diagrams, Figs. 28 and 29, present interesting contrasts with all which have preceded. The intercepts for silica have

drawn in, because of the increasing basicity. The alumina has decidedly shrunk as have the alkalies, indicating the waning amounts of the feldspars. The iron, lime and magnesia on the contrary are much greater, and thus emphasize the increase of the dark silicates.



FIGS. 28 AND 29. Diagrams illustrating the chemical composition of the basalts, which are given in the above table of analyses. Fig. 28 is based on molecular ratios; Fig. 29 on percentages.

General Description.—The Basalt series marks a decided step toward the basic extreme of the igneous rocks. The dark-colored silicates are now in excess and give the chief characters to the rocks. Augite and olivine are the ones of greatest importance, hornblende being very rare, and biotite scarcely known. The feldspars appear as the more basic plagioclases, labradorite to anorthite. Magnetite is a prominent component although usually too small to be recognized by the eye alone. The prevailing colors of the basalts are dark grays and blacks. When red or green the color is due to the advance of alteration. The fusing points are comparatively low, being in the neighborhood of 1940° F. (1060° C.). Glassy varieties are rare, although slaggy crusts and scorias are not unusual. The tendency to crystallize has been marked and irresistible during the process of cooling.

The textures are much more commonly felsitic than with the other groups, but porphyritic varieties are often met. The *Basalts proper* are felsitic, or, rather rarely, somewhat porphyritic rocks, and often cellular because of their crystallization as surface flows. The crusts upon these streams of basic lava may be very scoriaceous because of the free expansion of the dissolved vapors but from a point not far below the surface and thence to the interior, the rock becomes increasingly dense. Such cellular development as has taken place is then manifested in scattered, rounded or almond-shaped cavities called amygdaloids from the Greek word for an almond, whose outlines they closely resemble. These cavities frequently become filled with secondary calcite, quartz or chlorite, but the rounded masses must not be mistaken for phenocrysts. The under as well as the upper portions of basaltic flows are provided with them and in the copper region of Lake Superior they attain decided importance, because they have occasionally furnished a place of deposition for copper.

Basalts are frequently dense and felsitic and exhibit no phenocrysts whatever. They must then be recognized by their dark colors, and high specific gravity. When the phenocrysts manifest themselves they are most commonly olivine with which augite may at times be recognized. If studied with the microscope the felsitic varieties are resolved into a finely crystalline mass of small augites, plagioclase rods and magnetites. A little glass may occasionally be detected.

With the development of phenocrysts in moderate numbers the basalts proper pass into the *Basalt-porphyries*, often called dolerites. Phenocrysts of augite and olivine become prominent features of the rock, but visible plagioclases are few. The cellular texture disappears and the rocks are dense and solid. The basalt-porphyries constitute the interiors of thick flows and often form dikes. Yet it happens much more frequently with these basaltic rocks than with those more acidic, that the interiors of thick flows, instead of becoming porphyritic, develop coarser and coarser, even textured varieties which must be treated with the granitoid members.

When phenocrysts are in marked excess over the groundmass and constitute the greater part of the rock, the *Gabbro-porphyries* result. The groundmass is then coarsely felsitic and becomes in-

creasingly coarse as the gabbros are approached. These rocks occur in deep-seated dikes and in the outer parts of laccoliths and thick intrusive sheets.

Synonyms and Relatives. — The name basalt is a very ancient term and has been explained in several ways. Many regard it as a corruption of basanites, which was used by Pliny, although it is uncertain to what rock he applied it. The Greek word for the black touchstone or Lydian stone used by the ancient jewellers is similar to this last form. Others refer it to Basan or Bashan, the kingdom of Og, as mentioned in the Old Testament, Deuteronomy III., 1. Again an Ethiopian word "basal," used by Pliny for an iron-bearing rock, has been suggested. Agricola in the sixteenth century gave it its present signification.

The basalts almost always have olivine as an essential component, but there are certain rather uncommon varieties which lack it, but which still have the dark silicate, augite, in excess over the plagioclose, and which therefore differ from the andesites. They are called olivine-free basalts, and mark a transition to the augite-andesites. Very rarely indeed, hornblende replaces the augite in basalts and then the rocks are called kulaites from the occurrence of this variety in the Kula basin, Lydia, Asia Minor, where they have been discovered and studied by H. S. Washington.

While the time-distinction was esteemed of weight by the students of rocks, the name basalt was restricted to those of Tertiary or later age. The pre-Tertiary representatives were then called augite-porphyrites if they lacked olivine, and melaphyre if they possessed it. Melaphyre still survives as a much used term but the time distinction no longer obtains recognition.

In rare instances nephelite and leucite are found in basalts when studied with the microscope. The two feldspathoids may appear, each by itself or both together and they may replace the plagioclase in part or in whole. These varieties cannot be distinguished from normal basalts without microscopic study. They have been named tephrite, leucite-tephrite, basanite, leucite basanite, nephelinite, leucitite, nephelite-basalt and leucite-basalt, all of which will be found defined in the Glossary. It is fruitless to attempt their study without the microscope. The most experienced observers might easily confound them with ordinary basalts.

At several localities in America and abroad a very extraordinary and abnormal variety of basalt has been met which has quartz, even as a visible phenocryst. This mineral has resulted either from some extraordinary circumstances attending early crystallization, so that quartz developed as a phenocryst, or else because with a percentage of silica at the upper ranges of the basalts, the ferromagnesian bases were in such amount as to leave an excess of silica after their basic compounds were formed. This residual silica then crystallized as quartz since it had no alternative. These chemical relations are however extremely unusual, and the rocks are exceptional in the highest degree.

Two other varieties of basalts may be mentioned at this point and at somewhat greater length because of their special mineralogical and chemical interest and their relations to corresponding granitoid types. Neither of them can be recognized with the eye alone as differing in any respect from the ordinary basalts, but when studied with the microscope they present great contrasts. In both, feldspars and feldspathoids practically or absolutely fail. We have left then the augitites, which consist of augite in a glassy groundmass, and the limburgites which have both augite and olivine in a similar groundmass. As the analyses will show these mineralogical results become possible when, with very low silica, the alkalies and alumina so far fail that they are taken up in the dark silicates or glassy base.

AUGITITES.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	Loss.	Sp. Gr.
1.	44.17	11.24	9.97	6.22	10.77	6.55	3.04	1.97	2.31	
2.	43.35	11.46	11.98	2.26	7.76	11.69	3.88	0.99	3.00	2.974

LIMBURGITE.

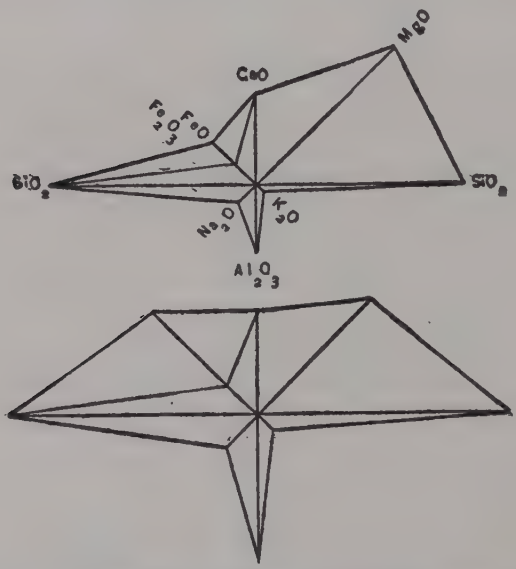
3.	42.06	12.18	2.67	7.89	11.29	11.47	5.10	1.07	3.08	2.968
4.	40.22	14.41	7.42	2.36	11.53	7.29	3.94	1.90	1.10	2.89

1. Augitite, Mariupol, Russia, J. Morozewicz, Neues Jahrb., 1900, I., 394. Also TiO_2 2.83. 2. Augitite, Hutberg, Bohemia, J. E. Hibsch, Tsch. Mitth., XIV., 110, 1894. Also TiO_2 2.43, P_2O_5 1.54. 3. Limburgite, Hahn, Hesse-Nassau, P. Jannasch, Sb. Berl. Akad. 1889, p. 1026; also TiO_2 1.93, P_2O_5, 34. 4. Limburgite, Palma, L. Van Werveke, Neues Jahrb. 1879, 485.

Figs. 30 and 31 are of special interest when compared with those of the basalts, Figs. 28 and 29. The great diminution in the intercept of alumina and the great increase in lime and mag-

nesia are very marked. The diagrams strongly resemble those of the pyroxenites and peridotites, given subsequently under Figs. 35–38.

There is some question in the minds of many observers as to whether the so-called glassy base of the augitites and limburgites really is a glass or whether it is not some isotropic mineral such as analcite. The basic magmas crystallize so readily as to make so much glass improbable. Analcite is the mineral usually thought of in this connection. It even gives a name to certain analcite-basalts, in which its presence has been positively shown.



FIGS. 30 AND 31. Diagrams illustrating the chemical composition of the limburgites which are given in the above table. Fig. 30 is based on molecular ratios; Fig. 31 on percentages.

The related rocks monchiquite, fourchite and ouachitite, will be found defined in the Glossary.

A very rare basaltic rock has the feldspathoid melilite as its chief feldspathic component. The magma is high in lime. The rock can only be identified with the microscope. Its related type alnoite is defined in the Glossary.

Alteration, Metamorphism. — The olivine of basaltic rocks is the first mineral to alter, and it soon becomes a network of serpentine

veinlets enclosing unchanged nuclei. The augite also passes readily into chlorite and finally the feldspar kaolinizes. The prevalence of green, chloritic products suggested the name greenstone for the old basaltic rocks. The basaltic rocks are extremely important in connection with metamorphism, and the iron-mining regions around Lake Superior present superb illustrations of the process. The augite has the greatest tendency to pass into green hornblende, by what is called a "paramorphic" change, *i. e.*, a change in the mineral without change in the chemical composition and without, as in pseudomorphs, preserving the original form. Under shearing stresses and movements, accompanied by this paramorphic change, the basaltic rocks pass into hornblende-schists, and even chlorite-schists or green-schists, losing their massive structure entirely and becoming a very different rock, and one that can be traced to its original with great difficulty. The widespread Catoctin schists of Virginia were derived in this way. The secondary hornblendic rocks are also called amphibolites.

Tuffs. — Basaltic tuffs, agglomerates, breccias, etc., are well known and often accompany the massive flows. They mark an explosive stage of eruption before or after the actual outpouring of lava.

Distribution. — Basaltic rocks are enormously developed in this country. The oldest strata are penetrated by numerous black, igneous dikes, in practically all their exposures. The New England seacoast is especially seamed by them, and hundreds may be met in a short distance. The Adirondacks and the White Mountains, the Highlands of New York and New Jersey, have many. In the East are the intruded sheets of Triassic basaltic rocks, largely diabases and described below. They may reach 500 feet in thickness, and form many of the most prominent landmarks, such as Cape Blomidon, N. S.; Mts. Tom and Holyoke, Mass.; East and West Rock, near New Haven, Conn., the Palisades on the Hudson, and many dikes in the Richmond, Va., and Deep River, N. C., coal fields. Around Lake Superior, both in the iron and in the copper regions, are still greater sheets, for many thousands of feet of basalt (diabase) are present on Keweenaw Point. On the north shore near Port Arthur, the head-lands of Thunder Bay exhibit superb examples. The iron-bearing strata

are penetrated by innumerable dikes. The greatest of all the American basaltic areas is, however, met in the Snake River region of southern Idaho and extends into eastern Oregon and Washington. Many thousands of square miles are covered with the dark lava and are locally called the "Lava Beds." In Colorado, as at the Table Mountains, near Golden and Fisher's Peak, near Trinidad, there are prominent sheets, and the same is true of many other points in this State. In New Mexico, Arizona and Texas they are also met. The volcanoes of the Sandwich Islands are basaltic. Basaltic rocks with nephelite are scarcely known in the United States. Some minor dikes in the East, a volcanic neck at Pilot Knob, near Austin, Texas, dikes and sheets in Uvalde Co., Texas, and a few dikes at Cripple Creek, Colorado, are practically the only localities yet identified. Leucitic rocks, more phonolitic than basaltic, are known in the Leucite Hills, Wyo., and in Arkansas. Of basaltic affinities they occur in New Jersey, but these and the nepheline rocks are of small practical moment, although of great scientific interest.

Basalts have quite as great development abroad as here. The islands off the north coast of Scotland are famous localities, and many of the volcanic regions of the continent are no less well provided. The lavas of Etna are chiefly basaltic, and those of Vesuvius are remarkable for their richness in leucite. In India are the great basalt fields of the Deccan, which are comparable in extent with those of the Snake River region of the West.

The Diabases.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	Loss.	Sp. Gr.
1.	54.52	19.10	2.83	5.89	7.25	3.92	3.73	2.30	0.59	2.7
2.	53.13	13.74	1.08	9.10	9.47	8.58	2.30	1.03	0.90	2.96
3.	49.28	15.92	1.91	10.20	7.44	5.99	3.40	0.72	3.90	2.86
4.	48.75	17.17	0.41	13.62	8.82	3.37	1.63	2.40	...	2.985
5.	46.28	12.96	4.67	6.06	10.12	8.71	3.75		3.34	2.921
6.	45.46	19.94	15.36	...	8.32	2.95	2.12	3.21	2.30	2.945

1. Diabase Hills, Nev., Woodward, 40th Parallel Surv., I., Table opposite p. 676. 2. Penn. R. R. cut, Jersey City, N. J., G. W. Hawes, A. J. S., iii., IX., 186. 3. Lake Saltonstall, Conn., Ibid. 4. Dike near Boston, Mass., W. H. Hobbs, Bull. Mus. Comp. Zool., XVI., 1. 5. Point Bonita, Calif., F. L. Ransome, Bull. Geol. Dept. Univ. Calif., I., 106. 6. Dike at Palmer Hill, Ausable Forks, N. Y., J. F. Kemp, Bull. 107, U. S. G. S., 26.

The diabases constitute a transitional group as regards texture from the felsitic basalts to the granitoid gabbros. The low fusing points and the great tendency to crystallize, which are possessed by the basaltic rocks, lead to the development of rather finely yet entirely and visibly crystallized aggregates of plagioclase, augite and often olivine, which in the refinements of texture differ from the true gabbros. The plagioclase is in elongated and sharply rectangular rods, especially when viewed with the microscope. The augite and olivine, in irregular development, are packed in between these interlacing rods. It is evident that the plagioclase,

FIG. 32. Diabasic texture, drawn from a microscopic slide of a diabase from Pigeon Pt., Minn. The actual field was three eighths inch (1 cm.). The rods of plagioclase are shown enclosing the augite, olivine and magnetite. The shaded mineral with light borders is augite; the shaded mineral with heavy borders is olivine. The black mineral is magnetite.

contrary to the usual order of crystallization, has abnormally finished its period before the ferro-magnesian silicates were much advanced, and that the latter have been forced to adapt themselves to whatever space remained. This result has often been reached in dikes and in the interiors of thick surface flows and intruded sheets, whose outer parts are characteristic basalts or even amygdaloidal varieties. The diabases are thus a peculiar phase of the granitoid texture as here defined, and their texture is called the diabasic or diabasic granular. They differ from the typical gab-

bros in that the feldspars of the latter are about as broad as long, and the succession of generations in the crystallization of the component minerals of the gabbros has been normal. Yet intermediate textures are known and gabbros are sometimes described as diabasic. When in the true diabases the augites become so abundant, large and coarsely crystalline, as to include the rectangular rods of plagioclase in a matrix of pyroxene, the texture is called ophitic. The ophitic texture is usually a matter for the microscope, but the diabasic can often be detected by the eye, and the feldspar rods may, in extreme cases, be an inch or more in length.

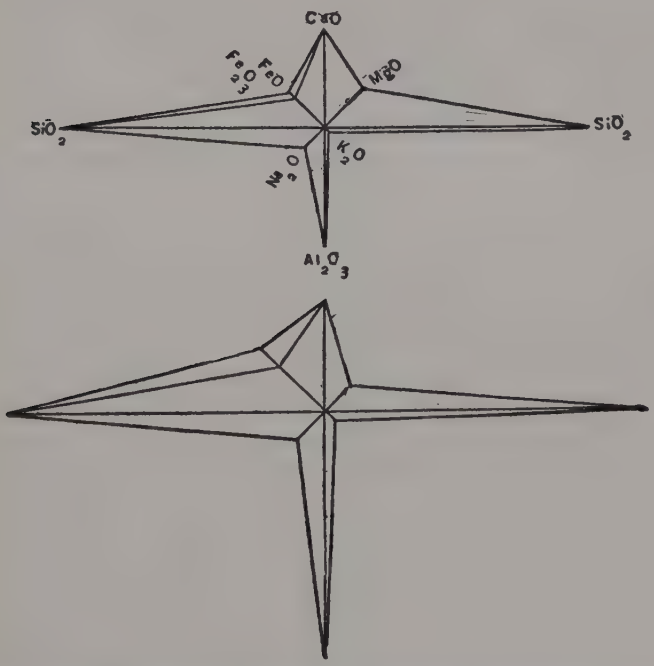
THE GABBROS.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	Loss.	Sp. Gr.
1.	59.55	25.62	0.75	...	7.73	tr.	5.09	0.96	0.45	2.66
2.	55.34	16.37	0.77	7.54	7.51	5.05	4.06	2.03	0.58	
3.	54.72	17.79	2.08	6.03	6.84	5.85	3.02	3.01	...	2.928
4.	54.47	26.45	1.30	0.67	10.80	0.69	4.37	0.92	0.53	2.72
5.	53.43	28.01	0.75	...	11.24	0.63	4.85	0.96	tr.	2.67
6.	52.14	29.17	...	3.26	10.81	0.76	3.02	0.98	0.58	
7.	49.15	21.90	6.60	4.54	8.22	3.03	3.83	1.61	1.92	
8.	48.02	17.50	1.80	7.83	13.16	10.21	1.48	tr.	0.79	
9.	46.85	19.72	3.22	7.99	13.10	7.75	1.56	0.09	0.56	
10.	46.85	18.00	6.16	8.76	10.17	8.43	2.19	0.09	0.30	3.097
11.	45.66	16.44	0.66	13.90	7.23	11.57	2.13	0.41	0.07	

1. Anorthosite, Chateau Richer, Canada, T. S. Hunt, Geology of Canada, 1863. 2. Norite, Cortlandt Series, Montrose Point, Hudson River, Anals. by Munn, for J. D. Dana, A. J. S., Aug., 1881, p. 104. 3. Gabbro, near Cornell Dam, Croton River, H. T. Vulté, for J. F. Kemp, unpublished. 4. Anorthosite, Summit of Mt. Marcy, Adirondacks, A. R. Leeds, 30th Ann. Rep. N. Y. State Museum, reprint, p. 14, 1876. 5. Anorthosite, Nain, Labrador, A. Wichmann, Z. d. d. g. Ges., 1884. 6. Gabbro, Iron Mtn., Wyo., 40th Parallel Surv., II., 14. 7. Gabbro, near Duluth, Minn., Streng, Neues Jahrb., 1876, 117. 8. Gabbro-diorite, Baltimore, Md., average of seventeen samples, Mackay for G. H. Williams, U. S. G. S., Bull. XXVIII., 39. 9. Gabbro, Baltimore average of twenty-three samples, ibid. 10. Gabbro, Southwest Adirondacks, C. H. Smyth, Jr., A. J. S., July, 1894, 61. 11. Gabbro, Northwest Minn., W. S. Bayley, Anals. by Stokes, Jour. Geol., I., 712.

Comments on the Analyses. — The range in composition presented by the gabbros is in many respects the same as that of the basalts, just as we would naturally expect; but there is one analysis (No. 1) which goes higher in silica. The rock is, however, a variant from the typical gabbros, as may be seen from the lack of iron and magnesia, leaving little else than the necessary elements for plagioclase. The same is true of Nos. 4 and 5. The

other analyses, however, exhibit very characteristic percentages, and upon studying them with care the reader will see that the aggregate of plagioclase, augite and often olivine, which is what constitutes the typical gabbro, must result from their crystallization. The percentages in silica range from 55 to 45. The alumina is in general quite high. In No. 6 it reaches a maximum for all the igneous rocks given. Except in 1, 4, 5 and 6, the bases iron, magnesia, lime and soda are quite high. Potash naturally is low, since orthoclase is usually present in small amount.



FIGS. 33 AND 34. Diagrams illustrating the chemical composition of the gabbros which are given in the above analyses. Fig. 33 is based on molecular ratios; Fig. 34 on percentages.

Figs. 33 and 34 are very like those of the basalts, Figs. 28 and 29. Lime, however, is relatively much greater than magnesia, owing in part to the fact that analyses 1, 4, 5 and 6 are included in the general average. The FeO is greater than the Fe_2O_3, just reversing the relations shown in the diagram of the basalts, and doubtless due to these particular selections of analyses. There

seems to be no fundamental reason why the basalts should differ from the gabbros in these respects.

Mineralogical Composition, Varieties. — The name gabbro is of Italian origin, and has been applied in recent years, and with growing favor to the great group of granitoid rocks which consists, in the typical cases, of plagioclase and pyroxene. The diabases, as was explained above, are texturally and mineralogically transitions from the basalts to the true gabbros. The so-called gabbro group is a very large and characteristically variable one. Originally the name gabbro was only applied to a mixture of plagioclase and the variety of monoclinic pyroxene called diallage, that has pinacoidal as well as prismatic cleavages, but of late years all granitoid, plutonic, pyroxene-plagioclase rocks are collectively spoken of as the gabbro group. In the typical gabbros the dark silicates predominate over the light-colored ones, but rocks are included in the general group, to which this restriction does not apply. In this particular the facts of field occurrence and natural relationship have broken down the sharpness of mineralogical definitions. At the acidic extreme we have in Canada and the Adirondacks enormous masses of rock that are practically pure, coarsely crystalline labradorite. Pyroxene is the dark silicate when any is present, but often it is insignificant. These pure feldspar rocks are best called *anorthosites*, from the French word for triclinic feldspar, but the word is not to be confused with anorthite, the lime feldspar, with which it has no special connection. An old and obsolete synonym of anorthosite is labradorite-rock, of interest because widely used in early reports on the Adirondacks. As monoclinic pyroxene increases the rocks pass into gabbros proper. More or less biotite and hornblende may also be present. If the pyroxene is orthorhombic we call the rock norite. Varieties with olivine are frequent, giving olivine-gabbro and olivine-norite. Gabbros and norites are not readily distinguished without the microscope, unless the bronzy appearance of hypersthene can be recognized. In the former case, gabbro is a good collective term. Norites were formerly called hypersthene rock, or hypersthene-fels, both of which are undesirable rock names. Gabbro intrusions of not too great extent for careful study have been observed to grow more basic toward the outer margins.

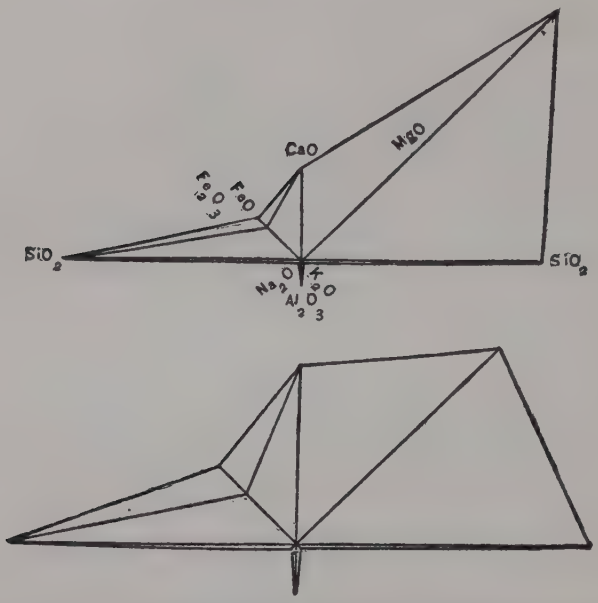
THE PYROXENITES AND PERIDOTITES.

Pyrox.	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	Loss.	Sp. Gr.
1.	55.14	0.25	3.48	4.73	8.39	26.66	0.30	...	...	
2.	53.98	1.32	1.41	3.90	15.47	22.59	...	...	0.83	3.301
3.	44.01	11.76	15.01	...	4.06	25.25	...	...	...	
Peridotite.										
4.	47.41	6.39	7.06	4.80	14.32	15.34	0.69	1.40	2.10	3.30
5.	46.03	9.27	2.72	9.94	3.53	25.04	1.48	0.87	0.64	3.228
6.	41.00	7.58	...	5.99	10.08	23.59	0.52	...	4.73	2.989
7.	36.80	4.16	...	8.33	8.63	25.98	0.17	2.48	0.51	
8.	33.84	5.88	7.04	5.16	9.52	22.96	0.33	2.04	7.50	
9.	29.81	2.01	5.16	4.35	7.69	32.41	0.11	0.20	8.92	2.78

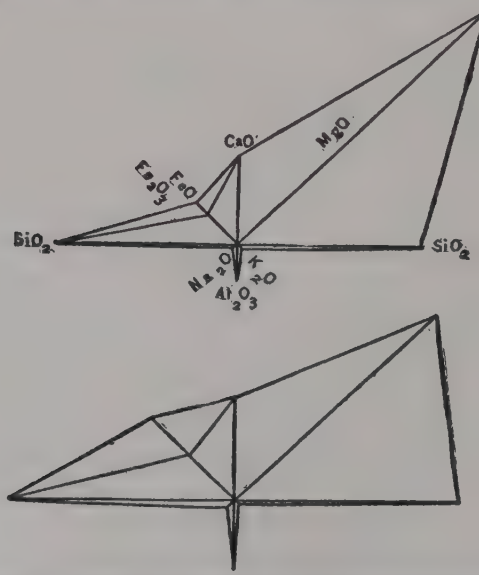
1. Pyroxenite, var. Websterite, Webster, N. C., E. A. Schneider for Geo. H. Williams, Amer. Geol., July, 1890, p. 41. 2. Pyroxenite, Baltimore, Md., T. M. Chatard for G. H. Williams, ibid. 3. Pyroxenite, Meadow Creek, Mont., Geo. P. Merrill, Proc. U. S. Natl. Mus., XVII., 658. 4. Peridotite, Cortland Series, Montrose Pt., N. Y., Emerson for G. H. Williams, A. J. S., Jan., 1886, 40. 5. Peridotite, Custer Co., Colo., L. G. Eakins for W. Cross, Proc. Colo. Sci. Soc., 1887, 245. 6. Peridotite, Baltimore, Md., L. Mackay for G. H. Williams, Amer. Geol., July, 1890, 39. 7. Peridotite, Dewitt, N. Y., H. S. Stokes for Darton and Kemp, Amer. Jour. Sci., June, 1895, 456. 8. Mica Peridotite, Crittenden Co., Ky., W. F. Hillebrand for J. S. Diller, A. J. S., Oct., 1892, 288. 9. Peridotite, Elliott Co., Ky., J. S. Diller, Bull. 38, U. S. G. S., p. 24.

Comments on the Analyses. — As compared with the gabbros the pyroxenites are characterized by the falling off in Al_2O_3, due to the disappearance of feldspar, and by the increase in CaO and MgO necessitated by the predominance of the pyroxenes. The peridotites reach a lower percentage of silica than any other igneous rocks so far cited, but if this is accompanied by high H_2O, allowance must be made for the relative decrease of the original SiO_2 because the rock has obviously changed to serpentine. The great percentages of MgO are very notable, and are due to the presence of much olivine, magnesian pyroxene and, in instances, biotite. Chromic oxide is also always present in small amounts, and oxides of nickel and cobalt are usually in perceptible quantity.

The diagrams illustrating the pyroxenites and peridotites are of much interest when compared with those of the gabbros. The intercepts for silica have drawn in; those for alumina and the alkalies have almost disappeared. The iron and lime have not changed very greatly, but the magnesia has expanded enormously, and has afforded a very significant and interesting set of figures.



FIGS. 35 AND 36. Diagrams illustrating the chemical composition of the pyroxenites, which are given in the above analyses. Fig. 35 is based on molecular ratios; Fig. 36 on percentages.



FIGS. 37 AND 38. Diagrams illustrating the chemical composition of the peridotites, which are given in the above analyses. Fig. 37 is based on molecular ratios; Fig. 38 on percentages.

The resemblance to the figures of the limburgites given above (Figs. 30 and 31) is close.

Mineralogical Composition, Varieties. — The gabbros pass insensibly, by the decrease of plagioclase, into the pyroxenites and peridotites, and in any great gabbro area all these are usually present, but they may occur also as independent masses. The pyroxenites are practically pyroxene, with little if any other minerals. There is some variety, according as the rock contains one or several of the following: enstatite, bronzite, hypersthene, diallage or augite; but with the unassisted eye, it is seldom that one can be sure of these distinctions, except as the orthorhombic pyroxenes exhibit a bronze luster. Hornblende, magnetite and pyrrhotite may also be present. With the accession of olivine, peridotite results, so named from the French word, peridot, for olivine, and a number of varieties have been made according as the olivine is associated with one or more of the minerals cited for pyroxenites. The list is given under Peridotite in the Glossary. The distinctions are however hardly possible without microscopic aid. As the extreme of peridotites we have a nearly pure olivine rock, called dunite, important in North Carolina. Much magnetite may be associated with peridotite; indeed at Cumberland Hill, R. I., there is enough to almost make the rock an ore. Chromite, too, is a frequent associate. As peridotites shade into a porphyritic texture, especially in dikes, they have been called picrites, and even additional varieties, such as kimberlite, have been made. Black hornblende, which is brown in thin sections, is frequent in both pyroxenites and peridotites, and may even form a rock itself, hornblendite. Dark brown biotite is also often present in considerable amount.

Some writers have regarded the pyroxenites and peridotites as of doubtful igneous origin and have placed them with metamorphic rocks, but from their frequent association with gabbro, and from their independent occurrence in dikes, there is no good reason to doubt their true, igneous nature.

A very rare granitoid rock, consisting of plagioclase, nepheline and ferro-magnesian silicates has been called theralite from the Greek verb to seek eagerly, because its discovery was anticipated by H. Rosenbusch before it was actually found by J. E. Wolff in the Crazy

Mountains, Montana. It is an extremely rare combination of minerals, but of special scientific interest because it corresponds among the granitoid rocks to the tephrites and basanites of the porphyritic.

Alteration, Metamorphism. — The gabbros alter chiefly by the formation of serpentine and chlorite from the dark silicates. The pyroxenites and peridotites change readily into serpentine, often with an intermediate stage as hornblende-schist. Under dynamic stresses, especially shearing, anorthosites and gabbros pass into gneissoid types, and in the process much garnet may be developed. This is especially true in the Adirondacks. The larger feldspars may be left in the gneisses as "eyes," or, to adopt the German term, as "Augen," affording Augen-gneiss, *i. e.*, gneisses with comparatively large lenticular feldspars. Much hornblende, especially in true gabbros, is often developed in the process. The basic members, the pyroxenites and peridotites develop into amphibolites or hornblende-schists, which latter often furnish very puzzling geological problems.

Distribution. — The anorthosites occur in several Canadian areas, as at the headwaters of the Saguenay River, and again north of Montreal; in the higher peaks of the Adirondacks and some of their outliers such as Mt. Marcy and its neighbors; and to the northeast of Laramie, Wyo., in the Laramie range. Gabbros are also present in vast quantity in the Adirondacks and are likewise well known in the White Mountains, in the famous Cortlandt series, near Peekskill, on the Hudson, and in the vicinity of Baltimore. Around Lake Superior gabbros are of great importance. The basal members of the Keweenawan system and other older intrusions are largely formed of them. Fine specimens can be had at Duluth. Gabbro is a characteristic wall rock of titaniferous magnetite. Pyroxenites occur as subordinate members of the gabbro areas, especially near Baltimore. Peridotites are in the same relations in the Cortlandt series, in the Baltimore area and in North Carolina. They are also known on Little Deer Island, Me.; at Cumberland Hill, R. I.; in dikes near Syracuse, N. Y.; at Presqu' Isle, near Marquette, Mich.; in Kentucky; in California and elsewhere in the West. When outlying dikes are met, far from any visible, parent mass of igneous rocks and in sedimentary walls, they are very frequently peridotite.

Abroad, anorthosites and gabbros are abundant in the Scandinavian peninsula, whose geology is in many respects like that of Canada and the Adirondacks. In the north of Scotland gabbros are of especial interest because they have been shown by Judd to be the deep-seated representatives of the surface basalts. On the continent they are important rocks in many localities. The same is true of Australia and such other parts of the world as have been studied. Of especial interest are the peridotite dikes in South Africa that have proved to be the matrix of the diamond.

Ultra-Basic Igneous Rocks. Meteorites.

A few ultra-basic igneous rocks are known in which the silica decreases almost to nil, and in which the bases, especially iron, are correspondingly high. They are in general rather to be considered as basic segregations in a cooling and crystallizing magma than as individual intrusions. The Cumberland Hill, R. I., so-called peridotite, cited above, has very little silica. Titaniferous ores have almost none, but they are often exceptionally rich in alumina. In a few cases metallic iron has been detected in basic igneous rocks, suggesting analogies with meteorities.

Meteorites are rare and only of scientific interest, but it is extremely suggestive that such silicates as are met in them are chiefly olivine and enstatite, minerals rather characteristic of very basic rocks. The commoner meteorites are an alloy of metallic iron and nickel, but some rare sulphides are occasionally present.

As filling out the theoretical series we cannot bar out water and ice. There is no reason why they should not be considered igneous rocks of extremely low fusing point, but they are so familiar that a simple reference to them is sufficient.

The Basalt-Peridotite Table. — The same general remarks which are given on p. 38, regarding the recasting of the analyses, apply also to this table, but some additional difficulties arise. Thus in No. 73.3, the limburgite, as described by the author, we have a rock with a glassy groundmass, in which pyroxene, olivine, magnetite, ilmenite and apatite are contained. In recasting we are practically forced to assume leucite, analcite and nephelite, and then to refer the substance of these to the glassy groundmass. In this case the recasting is only a remote approximation. By study of the table we see that quartz appears sometimes in the medium or basic rocks. Orthoclase also maintains a subordinate place. Plagioclase, except in the limburgite, pyroxenite and peridotite, is, as a rule, the most abundant mineral and in it the anorthite molecule predominates. Herein lies the marked contrast with the dacite-diorite series. In the anorthosite No. 78.4, the plagioclase reaches its culmination, constituting 87.1 per cent. of the volume of the rock, and with the orthoclase and quartz, 94.9 or say 95 per cent. The anorthosites thus furnish a very peculiar magma, of unusual scientific interest. If the loss is counted as a light-colored mineral we obtain our maximum of 96.2, leaving only 3.8 for the pyroxene and magnetite. No. 78.7 is next in percentage of light-colored minerals (86.5 per cent. by volume) and is the famous gabbro of Duluth, Minn., with its unusual amounts of orthoclase. From these values we drop to a minimum for the basalts of 72.2 and for the gabbros of 66.1. In the well-known diabase of the Palisades, N. J., No. 76.2, there is 56.9. We see thus that the light-colored minerals preponderate in these rocks, but as the feldspar is sometimes a green or red, the rocks are darker than we might expect from the proportions given. In the well-crystallized, feldspar-free rocks relations change. The one pyroxenite cited has 93.3 per cent. of dark minerals. The peridotites are 81.6 and 98 respectively. The last named rock, a curious peridotite dike from Kentucky has only apatite which may be considered a light-colored mineral.

Recalling the remarks made upon the preceding tables as well as the one just discussed we are impressed with the very general predominance of light-colored minerals in the igneous rocks, a characteristic which only changes in the decidedly basic.

	Basalt.				Limburgite.		Diabase.			Gabbro.					Pyroxenite.		Peridotite.			
	69.1*		69.6		69.10		73.3†		76.2		78.1		78.4		78.7		78.9		81.2		81.5		81.8	
SiO_2	57.25		50.38		47.54		42.06		53.13		54.72		54.47		49.15		46.85		53.98		46.03		33.84	
Al_2O_3	16.45		19.83		19.52		12.18		13.74		17.79		26.45		21.90		19.72		1.32		9.27		5.88	
Fe_2O_3	1.67		6.05		4.24		2.67		1.08		2.08		1.30		6.60		3.22		1.41		2.72		7.04	
FeO	4.72		2.00		6.95		7.89		9.10		6.03		.67		4.54		7.99		3.90		9.94		5.16	
MgO	6.74		5.36		6.66		11.47		8.58		5.85		.69		3.03		7.75		22.59		25.04		22.96	
CaO	7.65		10.03		11.70		11.29		9.47		6.84		10.80		8.22		13.10		15.47		3.53		9.52	
Na_2O	3.00		2.15		3.09		5.10		2.30		3.02		4.37		3.83		1.56				1.48		.33	
K_2O	1.57		1.76		.16		1.07		1.03		3.01		.92		1.61		.09				.87		2.04	
Loss	.45		1.37				3.08		.90				.53		1.92		.56		.83		.64		7.50	
Total	99.38		98.93		99.86		99.08		99.33		99.34		100.20		100.80		100.84		99.50		99.52		94.27‡	
	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.	Wt.	Vol.
Quartz	6.5	6.7	4.1	4.4					.7	.8			2.5	2.5					0.2	0.2				
Orthoclase	9.6	10.6	10.6	11.8	.6	.7			6.1	7.0	17.8	20.0	5.0	5.3	9.5	10.2	.6	.7						
Albite	25.2	28.1	17.8	19.4	26.2	30.0			19.4	21.5	25.2	28.2	36.7	38.0	32.0	33.6	13.1	14.7						
Anorthite	26.7	27.0	39.2	40.0	38.9	41.5			23.9	25.0	26.1	26.4	50.3	49.1	38.1	37.5	46.4	49.0	3.3	3.9	16.1	18.4		
Analcite							25.6	31.7											Biotite		14.1	14.9	12.7	12.1
Pyrox. (Amph.)	28.7	25.2	19.1	17.0	12.2	11.3	25.2	23.5	46.8	42.2	27.1	23.8	3.2	2.7	4.8	4.1	24.2	22.1	92.8	92.0	42.1	41.6	17.0	15.3
Olivine					15.8	13.0	27.1	22.5							4.9	4.2	11.3	9.1			18.4	16.2		
Serpentine																					5.0	6.4	38.0	43.7
Magnetite	2.3	1.3	6.2	3.4	6.0	3.5	3.9	2.3	1.6	.9	3.0	1.6	1.9	1.1	9.5	5.2	4.6	2.7	2.1	1.3	3.9	2.5		
Loss	.4	1.1	1.4	4.0			1.0	3.0	0.9	2.6			.5	1.3	1.9	5.2	0.6	1.7	.8	2.6				
Total	99.3	100.0	98.4	100.0	99.7	100.0	99.2	100.0	99.4	100.0	99.2	100.	100.1	100.0	100.7	100.0	100.8	100.0	99.0	100.0	99.6	100.0	98.8	100.0§
Light-colored Minerals	68.3	73.5	73.1	79.6	65.7	72.2	39.3	49.5	51.0	56.9	69.1	74.6	95.0	96.2	81.5	86.5	60.7	66.1	4.1	6.7	16.1	18.4	2.2	2.0
Dark-colored Minerals	31.0	26.5	25.3	20.4	34.0	27.8	59.9	50.5	48.4	43.1	30.1	25.4	5.1	3.8	19.2	13.5	40.1	33.9	94.9	93.3	83.5	81.6	96.6	98.0

* In these double numbers, the first refers to the page in the Handbook and the second to the number of the analysis where first given.

† No. 73.3 contains also TiO_2 1.93 and P_2O_5 .34 both of which were used in recasting. Of the minerals there were calculated also, and respectively by Wt. and Vol. leucite 5.23, 6.30; Nephelite, 6.82, 7.81; Ilmenite, 3.7, 2.21; Apatite, .7; .7. The substance of the leucite, analcite and nephelite, appears in the rock as a glassy ground mass. Distinctions of light- and dark-colored minerals fail in this rock.

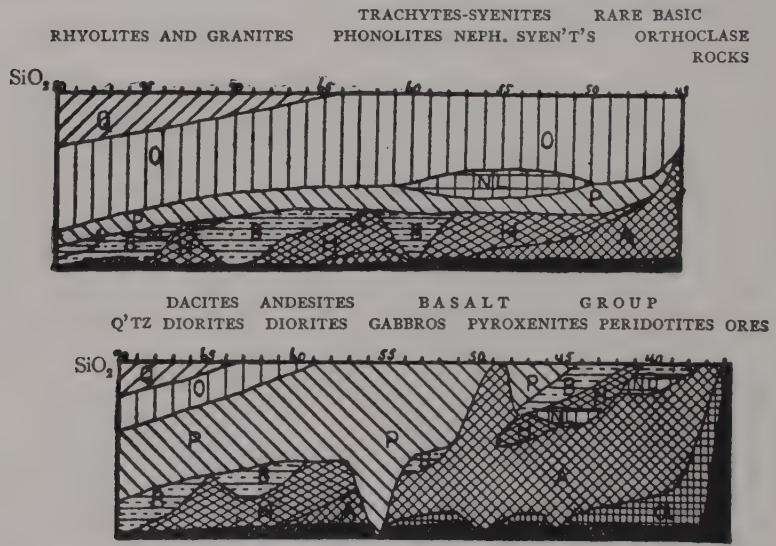
‡ The last chemical analysis, 81.8, contains also TiO_2 3.78; Cr_2O_3 .18; MnO .16; NiO .10; P_2O_5 .89; which were used in recasting.

§ The last analysis yields also in minerals, chlorite wt. 21.6, vol. 22.2; ilmenite, 7.1 and 4.6; apatite, 2.2 and 2.0, the only light-colored mineral; chromite, .2 or .1.

CHAPTER VI.

Remarks in Review of the Igneous Rocks.

Chemical Composition. — Igneous magmas vary from about 80 per cent. silica as a maximum to practically none as a minimum, but important rocks rarely drop below 40 per cent. Alumina is highest in the anorthosites or feldspathic gabbros, where it may exceed 25 per cent. It is lowest in the pyroxenites and may be less than 1 per cent. The oxides of iron are almost lacking in the highly siliceous, but may reach beyond 20 per cent. in the basaltic



Figs. 39 and 40. — Diagram intended to illustrate graphically the mineralogical composition of the igneous rocks. The numbers indicate percentages in silica. The upper diagram, Fig. 39, includes the orthoclase rocks, the lower, Fig. 40, the plagioclase and non-feldspathic ones. Q is quartz; O, orthoclase; NL, nephelite and leucite; P, plagioclase; M, muscovite; B, biotite; H, hornblende; A, augite; Ol, olivine; the black area, magnetite, pyrrhotite, and other metallic minerals.

rocks, and with TiO_2 may be nearly 100 per cent. in some igneous iron ores. Lime attains its maximum of 12–15 per cent. in the gabbros and pyroxenites, while magnesia in the pyroxenites and peridotites may even surpass 25 per cent. Potash is most abundant in the orthoclase and leucite rocks; soda in those with nephe-

lite. Combined alkalies may reach 15 per cent. in the phonolites and nephelite syenites. In general they are, however, about 4–10, and may practically fail. Water in quantities over 1 per cent. as a rule is an indication of decay, but in the pitchstones this is not positively true, for the water reaches close to 10 per cent. and the rocks are apparently unaltered.

Texture. — All of the typical textures are easily recognized in characteristic development, but the glassy shade insensibly into the felsitic, the felsitic into the porphyritic, and the porphyritic into the granitoid. There are, therefore, intermediate forms that are difficult to classify. Yet, on the whole, the four textures are the most satisfactory basis for classification, and as a guide, in accordance with which to study. Chemical composition being the same, *texture is a result of the physical conditions surrounding the magma at the time of crystallization and of the presence of mineralizers.*

Mineralogy. — The above diagrams, with a reasonable approximation to the truth, illustrate the quantitative mineralogy of the igneous rocks. A section cut through the charts at any one point expresses the relative amounts as well as kinds of the several minerals in the rocks whose names are along the top lines, and whose percentages in silica are approximately shown. No mention is made of texture. In the orthoclase rocks quartz disappears at about 65% SiO_2, while orthoclase continues to the end; plagioclase in small amount is quite constantly present throughout the series. Nephelite and leucite come in as indicated. Muscovite appears only in the more acidic granites. Biotite and hornblende vary in relative quantity, but toward the basic end both yield to augite. The rocks at the basic end are chiefly those recently discovered by Weed and Pirsson in Montana, by Iddings in the Yellowstone Park and by Lawson in the Rainy Lake region. In the plagioclase and non-feldspathic rocks quartz and orthoclase soon run out, so far as any notable or regular amount is concerned. Plagioclase holds along to about 45% SiO_2, and at about 55% SiO_2 may in the anorthosites be the only mineral present. Biotite and hornblende are present all the way through, but toward the basic end they tend to yield in importance to augite, which latter in some pyroxenites, at about 49% SiO_2, may be the only silicate present. Olivine begins to appear at 55% and steadily increases with occa-

sional lapses almost to the end, where it may be the chief mineral. The ores, as the extreme case, and without regard to silica, increase so as to be the only minerals in the rock, forming thus the theoretical, basic limit. The diagrams also emphasize the fact that igneous rocks shade into one another by imperceptible gradations, and this is true of the orthoclase and plagioclase groups themselves, although not suggested by the separation of the two in the drawings. The continuation of the orthoclase series to a basic extreme is a fact that we have only appreciated in very recent years.

A careful scrutiny of analyses and mineralogical composition leads to the conclusion that practically the same magma may, under different physical conditions of crystallization, afford mineralogical aggregates that vary considerably in the proportions of the several minerals — now yielding more hornblende, again more augite, and even affording quartz in a basalt. Hence, analyses in different groups overlap more or less, and the difficulty of drawing sharp lines of distinction is increased. Yet, allowing for this variation chemical composition determines the resulting mineralogical aggregate and is fairly characteristic.

Determination of Igneous Rocks. — In determining an igneous rock, the texture should first be regarded, next the feldspars. If orthoclase prevails, the presence or absence of quartz establishes the rock. If plagioclase prevails, we look for biotite, hornblende, pyroxene and olivine. If no feldspar is present, we look for the presence or absence of olivine. On this basis the table on page 23 is to be used — there are, however, many finely crystalline rocks which elude the power of the unassisted eye. If of light shades, they can generally be referred with reasonable correctness to the rhyolites, trachytes, felsites or andesites. If dark, they are probably basaltic in their nature, and the name "trap" is a very useful and sufficiently non-committal term. Care should be exercised not to confuse the porphyritic rocks having angular phenocrysts with the amygdaloids, or the rocks whose almond-shaped cavities, produced by expanding steam, have been filled by later introduced calcite, or quartz, or other secondary minerals. While books are of great assistance, really the only way to become properly familiar with rocks is to use the books in connection with correctly labeled and sufficiently complete study collections.

Field Observations. — A rock is not to be considered by any intelligent observer as a dead, inert mass in nature, but as an important participant in the ceaseless round of changes which confront us on every side. Familiarity with specimens and varieties in collections ought always to be followed by observation in the field. We have all grown to believe that in limited areas igneous rocks, however varied they may be, are yet intimately related in their origin, or are bound together by ties of kinship, "consanguinity," as Iddings has called it. Some regions like eastern Montana and the Black Hills have especial richness of high soda or potash magmas, giving rise to nephelite and leucite rocks, and sodalite syenites; Colorado, Utah and New Mexico have wonderful and enormous laccolites of andesites (porphyrites). The Pacific coast in South America has andesites in vast extent from active volcanoes, and in North America from extinct cones. Idaho, Oregon and Washington are marked by basalts. The Atlantic coast region has a long series of very ancient volcanoes, that preceded the early fossiliferous strata from Newfoundland to North Carolina and that yielded nearly the entire series of the volcanic rocks. In the Adirondacks, on the Hudson near Peekskill, near Baltimore, and around Lake Superior we find the members of the gabbro family; while near tidewater along the Atlantic seaboard we have granites, almost all with biotite. Such facts as these suggested the creation of the term "petrographic provinces," to J. W. Judd, in the endeavor to suggest these kinships of magmas in certain limited districts. There are many others even in North America that could be cited, but the above will suffice to remind the reader that these broader relationships should be always before him while extending his acquaintance with rocks as they occur in the natural world about him.

CHAPTER VII.

The Aqueous and Eolian Rocks. Introduction. The Breccias and Mechanical Sediments Not Limestones.

The members of this, the second grand division, are much simpler, and, as a general thing, much easier to identify and to understand than are the igneous. No single term is comprehensive enough to include them all, and even the double one selected above in the endeavor to embrace as many as possible, and to avoid the multiplication of grand divisions, still falls short of including several. Nevertheless, those not embraced (the breccias) are of limited distribution, and, for many reasons, go best with the other fragmental rocks, even if, strictly speaking, they are neither aqueous nor eolian in origin. Sedimentary is the most useful term, and is universally applied as a partial synonym of the above, for it fairly includes the most important members of the series, but the rocks deposited from solution and the eolian rocks can hardly be understood by it.

The rocks will be taken up under the following groups:

I. Breccias and Mechanical Sediments, not Limestones.
II. Limestones.
III. Organic Remains, not Limestones.
IV. Precipitates from Solution.

The limestones are reserved for a special group, although they belong in instances to each of the other three. They form, however, such an important series in their scientific and practical relations, that it is in many respects advantageous to take them all up together.

I. Breccias and Mechanical Sediments, not Limestones.

Group I. is described in order from coarse to fine according to the following series, minor varieties not cited in the table being mentioned in the text under their nearest relatives.

Coarse			to		Fine.
Breccia.	Gravel and Conglomerate.	Sand and Sandstone.	Argillaceous Sandstone. Calcareous Sandstone.	Silt and Shale. Calcareous Shale.	Clay. Marl.

Breccias.

The word breccia is of Italian origin and is used to describe aggregates of *angular* fragments cemented together into a coherent mass. The breccias cannot all be properly considered to be either aqueous or eolian, and some have already been referred to under the fragmental igneous rocks. Oftentimes they resemble conglomerates, but, unless formed of fragments of some soluble rock, whose edges have become rounded by solution, there is no difficulty in distinguishing them. Breccias, as regards their angular fragments and interstitial filling, may be of the same materials or of different ones. We may distinguish *Friction breccias* (Fault breccias), *Talus breccias*, and, for the sake of completeness, may also mention here *Eruptive breccias*.

Friction breccias are caused during earth-movements by the rubbing of the walls of a fault on each other, and by the consequent crushing of the rock. The crushed material of finest grade fills in the interstices between the coarser angular fragments, and all the aggregate is soon cemented together by circulating, mineral waters. Such breccias occur in all rocks and are a frequent source of ores, which are introduced into the interstices by infiltrating solutions. Quartz and calcite are the commonest cements.

Talus breccias are formed by the angular débris that falls at the foot of cliffs and that becomes cemented together by circulating waters, chiefly those charged with lime.

Eruptive breccias may be produced either by the consolidation of coarse and fine, fragmental ejectments like tuffs, or by an erupting sheet or dike that gathers in from the wall rock sufficient fragments as inclusions to make up the greater part of its substance. These are finally cemented together by the igneous rock itself and afford curious and interesting aggregates, oftentimes representing all the rocks through which the dike has forced its way to the surface. A crust may also chill on a lava stream, and when an added impulse starts anew the flowing, the crust may be shattered into an eruptive breccia of a still different type.

We often speak of breccias as "brecciated limestone," "brecciated gneiss," or some other rock, thus making prominent the character of the original. When the fragments and the cement are con-

trasted in color, very beautiful ornamental stones result, which may be susceptible of a high polish.

A moment's consideration of the above methods of origin will convince the reader that breccias, except as formed of loose, volcanic ejectamenta, are of very limited occurrenee. Although deeply buried rocks that share in profound earth movements often suffer crushing and brecciation on a large scale, the effects are chiefly detected by microscopical study.

Generalities Regarding Sedimentation.

In the production of the rocks next taken up, moving water plays so prominent a part that its general laws are described by way of necessary introduction. All streams or currents charged with suspended materials exercise a sorting action during the deposition of their loads. With materials of the same density the sorting will grade the deposit according to the sizes of the particles. With materials of different densities, smaller particles of heavier substances will be mixed with larger particles of lighter ones. Assuming a swift current, we readily see that, when it slows up, the large and heavy fragments drop first of all; then the smaller fragments of the heavier materials and the larger ones of those successively lighter, until at last the smallest particles of the lightest alone remain in suspension. It is also important to bear in mind that the transporting ability of a current varies with the sixth power of the velocity. Thus if we have a current of proper velocity to move a cube of quartz one inch on the edge, and then double the velocity, the faster current can move one sixty-four times as large; that is four times as long, or four inches on the edge. An appreciation of this law makes the size of boulders moved by many streams, in times of flood, less surprising. On the other hand, when the suspended material becomes excessively fine, the ratio of its surface to its volume is so extremely high that adhesion, or chemical action akin to hydration, or some other influence not well understood, operates in pure, fresh waters, so as to practically render sedimentation impossible, even if the medium be perfectly quiet. W. M. Brewer has shown by a series of experiments with all sorts of clays, lasting over many years, that if we introduce into such an emulsion a mineral acid or a solution

of salt or of some alkali, the turbidity clears with remarkable quickness. When, therefore, sediment-laden streams flow into the ocean, or into salt lakes, even the finest part of their load speedily settles out.

While we may state thus simply the laws of sedimentation, we must not expect in Nature such well-sorted and differentiated results as would at first thought appear to be the rule. Of rivers and shore currents — the two great transporting agents — the former are subject to floods and freshets, giving enormously increased efficiency for limited periods, and again to droughts, with the same at a minimum. Hence varying sediments overlap and are involved together. Eddies and quiet portions in the streams themselves contribute further confusion, and an intermingling of coarse and fine materials. Shore currents have parallel increases of violence in times of high wind and storms, and sink again in times of calm.

Eolian deposits are subject to even greater fluctuation, and their irregularities are more pronounced than those of the true Aqueous. Both these classes of rocks are marked by a more or less perfect arrangement of their materials in layers. The layers give rise to regular beds in deposits from quiet and uniform currents, and, although in those from swift ones they are very irregular, as explained above, nevertheless, *bedding*, or *stratification*, is in the highest degree characteristic of the Aqueous and Eolian grand division.

When in the presence of these sedimentary rocks in the field, the observer should always appreciate that they reproduce past conditions, and that they indicate the former presence of water, either in a state of agitation and with high transporting power for the coarse varieties, or as quiet reaches in which were laid down the finer deposits. Rightly approaching and interpreting them, we may see that the ocean has advanced across the land in times of submergence, leaving behind its widening trail of shore gravels, now conglomerates; that these have been followed up and buried first by fine offshore sediments, and later by the remains of organisms now appearing as limestones, until succeeding elevation causes the waters again to retreat and prepare the way for another "cycle of deposition."

Gravels and Conglomerates.

Loose aggregates of rounded and water-worn pebbles and boulders are called gravels, and when they become cemented together into coherent rocks they form conglomerates. Sand almost always fills the interstices. Silica, calcite and limonite are the commonest cements. The component pebbles are of all sorts of rock depending on the ledges that have supplied them, hard rocks of course predominating. Rounded fragments of vein quartz are especially frequent. Gravels and conglomerates, if of limited extent, indicate the former presence of swift streams; if of wide area they suggest the former existence of sea beaches and the advance of the sea over the land. Component pebbles are of course older than the conglomerate itself, and if igneous, they may establish the age of the intrusion as older than the conglomerate. Fossiliferous boulders prove the age of the conglomerate as later than their parent strata. Under favorable circumstances gravels may be cemented to conglomerates in a comparatively few years. Conglomerates are exclusively aqueous. Gravels and conglomerates graduate by imperceptible stages into pebbly sands and sandstones, and these into typical sands and sandstones. Notably unsorted aggregates of relatively large and more or less angular boulders in fine sands or clay indicate glacial action.

Metamorphism. — Under dynamic stresses, especially in the nature of pressure and shearing, the pebbles of a conglomerate may be flattened and rolled out into lenses, and these are often observed. If the pebbles are feldspathic as is the case in those from granite ledges, and if the interstitial filling is aluminous and not purely quartzose as in the commonest cases, conglomerates, when recrystallized, may pass into augen-gneisses with their characteristic "augen," or "eyes" of feldspar and quartz that but faintly suggest their original character. Excessive metamorphism may further develop types closely simulating granite, forming thus the so-called "recomposed granite" of the Lake Superior regions.

Occurrence. — Gravels are too familiar to require further reference. Conglomerates are met in all extended sedimentary series. Our greatest one lies at the base of the productive Coal Measures of Pennsylvania and adjacent States. It is properly called the

"Great Conglomerate." Remarkable ones with squeezed pebbles are met in the Marquette iron region of Michigan. In Central Massachusetts there is an augen-gneiss that has been derived from a Cambrian conglomerate. It is quarried at Munson, and sold as granite, and is a widely known building stone. Around Narragansett Bay, R. I., are conglomerates, in part at least of Carboniferous age, in all stages in the progress to gneiss.

SANDS AND SANDSTONES.

	SiO_2	Al_2O_3	FeO Fe_2O_3	MnO	CaO	MgO	K_2O	Na_2O	Loss.	Sp. Gr.
1.	99.78	0.22	...	...	...	...	...	...	...	
2.	98.84	0.17	0.34	tr.	tr.	tr.	...	...	0.23	
3.	99.62	...	0.13	0.7	...	...	...	...	...	
4.	99.47	0.17	0.12	...	0.90	0.50	0.07	0.15	0.12	2.647
5.	95.85	2.64		...	0.81	0.08	...	...	0.45	(2.245)
6.	94.73	0.36	2.64	...	0.38	0.36	...	...	0.83	
7.	91.67	6.92	tr.	...	0.28	0.34	...	...	1.17	2.240
8.	82.52	7.07	3.55	1.42	1.83	tr.	tr.	tr.	3.61	
9.	69.94	13.15	2.48	0.70	3.09	tr.	3.30	5.43	1.01	(2.36)

1. Sand from Cambrian Quartzite, Chesire, Mass., S. Dana Hayes, *Mineral Resources*, 1883–'84, p. 962. 2. Oriskany Sandstone, Juniata Valley, Penna. A. S. McCreath, *Idem*. 3. Siluro-Cambrian saccharoidal sandstone, Crystal City, Mo. Analyzed by Glass Co., 0.22 not determined, *Idem*. 4. Novaculite, Rockport, Ark. R. N. Brackett, for L. S. Griswold, Geol. Ark., 1890, III., 161. 5. Salmon-red Triassic Sandstone, Glencoe, Colo. Quoted by G. P. Merrill, "Stones for Building and Decoration," p. 420. The Sp. Gr. is of one from Ralston, near by. 6. Cambrian red Sandstone, Portage Lake, Mich., *Idem*. 7 Light-gray sub-carboniferous sandstone, near Cleveland, Ohio, *Idem*. 8. Olive-green carboniferous sandstone, Dorchester, N. B., *Idem*. 9. Red triassic sandstone (brownstone, arkose), Portland, Conn., *Idem*.

Comments on the Analyses. — The first three illustrate the purity of the sand in exceptional cases. We may properly infer that the sediments were derived either from preëxisting sandstones, that had already been once sorted and separated from their aluminous ingredients, or from excessively weathered and kaolinized quartzose rocks, such that the feldspar had entirely passed into clay, and had been eliminated in deposition. No. 4 is a novaculite, and is an excessively fine, fragmental deposit. Nos. 5, 6 and 9 are red sandstones, and indicate the comparatively small percentage of iron oxides that may cause a deep coloration. No. 7 is free from iron, but has some aluminous material, evidently a very pure clay, from the lack of iron. No. 8 has its iron as protoxide, for the rock is a green variety. Its manganese oxide is worthy of remark. No.

9 is a feldspathic sandstone, or arkose, whose analysis, except that the Al_2O_3 is low and the CaO rather high, might answer for a granite.

The specific gravity of sandstones varies widely. Quartz itself is 2.6–2.66, and specially dense sandstones reach 2.5, but, being characteristically porous rocks, the usual range is 2.2–2.4. They often go lower and many even reach 1.8.

Mineralogical Composition, Varieties. — The mechanical sediments whose predominant particles are finer than pebbles, and yet, in most cases, of notable size, are grouped under this head. They are found in all stages of coherence, from loose sands to excessively hard, metamorphic rocks called quartzites. Quartz is much the commonest mineral that contributes the grains, as it is the most resistant of the common rock-making minerals. In river sands the grains are angular, but in those continually washed together on a sea beach, they become more or less rounded. Garnets, magnetite, zircon and other hard and resistant minerals are widely distributed in small quantities. Feldspathic sands also occur, and when they are compacted into firm rock they are called arkose. As in the conglomerates, the cementing materials of sandstones are silica, calcite and limonite, but in many the character or cause of the bond is rather obscure. Those with siliceous cement yield the most durable stone for structural purposes; those with ferruginous afford the greatest range of colors, such as olive-green, yellow, brown, and red. Calcareous cements may be detected by their feeble effervescence. Sandstones entirely formed of calcareous fragments are known, but are described under limestone.

A curious and exceptional rock is the novaculite, that is extensively developed in Arkansas. It was long thought to be allied to the cherts, which it much resembles, but microscopic investigation has led Griswold to determine it to be a finely fragmental deposit of quartz grains, practically a siliceous ooze. In fineness it is parallel with the clays, but it contains little else than silica.

Aqueous sandstones generally exhibit well-marked bedding planes, although cases are familiar in which the bedding is excessively coarse and the layers are extremely thick. Swirling eddies in the original stream or currents give rise to cross-bedding and various irregularities. In fact, all the phenomena of beaches and

stream-bottoms, such as ripple-marks, worm-borings, shells, etc., are preserved in sandstones.

Eolian sands are usually of aqueous deposition in their original condition, but they are afterwards taken up by the wind and driven along as dunes and dust into more or less remote districts. When they finally reach a state of rest and consolidate, they have very irregular stratification, cross-bedding, swirling curves, pinching and swelling layers and other characteristic phenomena. Finer varieties afford a surface deposit that is generally called "loess," and that may lack all stratification. More or less water-transported material is also intermingled, making the term one of not particularly sharp definition. This mixed character has made the loess of many localities a rather puzzling geological problem. It is always loosely textured and is important in its relations to agriculture.

Sands and sandstones pass by insensible gradations into the varieties in the upper line of the series shown in the tabulation on p. 92 by the increasing admixture of clayey or argillaceous materials. The base is kaolin, Al_2O_3, $2SiO_2$, $2H_2O$, a mineral that forms microscopic, scaly crystals and that has the property of plasticity, and this property it lends to the last members of the series, which in exceptional cases may contain little else. The lower series passes gradually into the fragmental limestones, by the increasing admixture of calcite.

Metamorphism. — The purer sandstones in metamorphism yield quartzites which are denser and harder than their originals, because by deposition of cementing quartz, the fragmental grains are very firmly bound together. The later deposited quartz often conforms to the optical and crystallographic properties of the grain around which it crystallizes. No sharp line divides sandstones and quartzites; they shade imperceptibly into one another. Less pure sandstones, if crushed and sheared in the metamorphic process, yield siliceous or quartz schists from the development of micaceous scales between the grains. Flexible sandstone or itacolumite has been thought to owe to them its property of bending, but it is now generally attributed to the interlocking of grains.

Occurrence. — Sandstones are so common in all extended geological sections as to deserve slight special mention. Next to limestones they are the most widely used of building stones in quantity,

although the money value of the annual output of granite is greater. The Potsdam sandstone of the Cambrian in New York and on the south shore of Lake Superior is extensively quarried. Other prominent sandstones are the Medina of New York, the Berea grit of the Subcarboniferous of Ohio; and the red and brown Triassic sandstones both of the Atlantic seaboard and the Rocky Mountains.

Argillaceous Sandstone, Shale, Clay.

	(a) SiO_2	(b) SiO_2	Al_2O_3	FeO Fe_2O_3	CaO	MgO	K_2O, Na_2O	(a) H_2O	(b) H_2O
Shale.									
1.		69.92	23.46	0.20	0.48	0.40	1.43	3.84	
2.		67.29	15.85	6.16	0.95	0.19	8.71	...	
3.		64.37	19.73	9.07	0.82	2.32	3.78	...	
4.		62.86	20.65	9.21	0.48	0.34	...	6.26	
5.		58.45	21.96	8.43	1.05	1.57	4.00	6.51	
6.		43.13	40.87	3.44	8.90	5.32	2.42	0.20	
Brick Clay.									
7.		81.71	9.81	3.80	0.48	0.26	...	3.91	
8.		75.88	11.22	5.04	0.48	0.35	...	6.76	
9.		65.14	13.38	7.65	2.18	2.36	8.51	...	
10.		62.00	18.10	9.11	...	...	...	5.66	
11.		57.80	22.60		1.85	1.07	...	12.68	
12.		53.77	20.49	9.23	2.04	4.22	9.60		
13.		45.73	29.69	6.86	0.44	1.01	3.42	12.86	
Potter's Clay.									
14.	27.68	36.58	22.95	1.28	0.45	0.37	1.96	6.74	2.05
15.	42.28	18.02	24.12	1.46	0.59	0.68	2.42	7.77	0.86
Fire Clay.									
16.		61.60	28.38	0.52	0.46	0.36	...	5.08	
17.	38.10	12.70	31.53	0.92	...	tr.	0.40	11.30	2.50
18.		45.29	40.07	1.07	0.26	0.08	0.48	13.18	
Residual Clay.									
19.		55.42	22.17	8.30	0.15	1.45	2.49	9.86	
20.		33.55	30.18	1.98	3.89	0.26	1.57	10.72	
Kaolinite.									
21.		46.50	39.57	...	...	...	...	13.93	

NOTE. Where two values of SiO_2 are given, the first is the combined silica, *i. e.* chiefly in kaolinite, and the second the free silica, which is practically comminuted quartz. Under H_2O, where two values are given, the first is combined water, likewise chiefly in kaolinite, the second is the free water, which has simply been absorbed.

1. Haydensville, Hocking Co., O. Quoted by H. Ries, XVI. Ann. Rep. Director U. S. Geol. Survey, Part IV., p. 572. 2. Hornellsville, Steuben Co., N. Y., *Ibid.*, 572. 3. Kansas City, Mo., *Ibid.*, 570. 4. Red Shale, Sharon, Mercer Co., Pa., *Ibid.*, 572. 5. Leavenworth, Kan., *Ibid.*, 570. 6. Clinton, Vermilion Co., Ind., *Ibid.*, 570. 7. Washington, Davies Co., Ind., *Idem*, 566. 8. Salem, Washington Co., Ind., *Idem*, 566. 9. Red Clay, Plattsburg, Clinton Co., N. Y., *Ibid.*, 568.

10. Red Clay, Lasalle, Ill., *Ibid.*, 564. 11. Rondout, N. Y., *Ibid.*, 568. 12. Brown Clay, Fisher's Is., N. Y., *Ibid.*, 568. 13. Hooversville, Somerset Co., Pa., *Ibid.*, 568. 14. Akron, O., *Ibid.*, 562. 15. East Liverpool, O., *Ibid.*, 562, also TiO_2, 1.20. 16. Woodbridge, N. J., *Ibid.*, 556. 17. Cheltenham, Mo., *Ibid.*, 556. 18. Woodland, Pa., *Ibid.*, 556. 19. Morrisville, Calhoun Co., Ala., *Ibid.*, 574. 20. Near Batesville, Ark., *Ibid.*, 574, also P_2O_5, 2.53. 21. Pure Kaolinite—$Al_2O_3\,2SiO_2,\,2H_2O$.

Comments on the Analyses. — The analyses are significant when compared with those of the sandstones on p. 97. It appears at once that there is a great decrease in silica, and a great increase in alumina, and, as a rule, in all the other bases and water. Among themselves there is wide variation, but by using No. 21, as indicating pure kaolin, it is possible to infer how much quartz sand is mingled with the clay, due allowance being made for the fragments of unaltered feldspar, as shown by the alkalies, for silicates, hydrous and anhydrous, involving iron, lime and magnesia, and for carbonates of lime, magnesia and iron. Shales and brick clays are shown to be comparatively impure admixtures of kaolinite and quartz; potter's clay is much less so, and fire-clay is little else than these two. No. 18 is practically pure kaolin.

Mineralogical Composition, Varieties. — The argillaceous sandstones have a finer grain than the sandstones proper, and tend to form thin but tough beds. They find their best examples in the flagstones of our eastern cities. Shales lack this coherence and break readily into irregular slabs and wedge-shaped fragments of no notable size. As sands give rise to sandstones, so on hardening and drying, muds and silts yield shales. Shales show all grades from gritty and coarse varieties to fine and even ones approximating clays. The finer shales when ground have the same plasticity as clay, and are often moulded and baked into brick, especially of the vitrified kinds for paving. Shales may be black from bituminous matter in them, and are then described as "bituminous." They grade into cannel coals, but great areas of them such as the Genesee Shale of New York and the Huron Shale of Ohio, have as much as 8 to 20 % hydrocarbons and yield quite copious products on distillation.

As the particles of quartz become finer and finer and not too abundant, the plasticity of the kaolinite presently asserts itself so that the shales pass into clays. In the most even and homogeneous grades, they show but slight grit to the teeth, but in coarser

varieties they are decidedly gritty even to the fingers. They are often separated into thin beds by layers of sand that mark the times of freshets during their formation and the attendant deposition of coarse material. Clays of earlier geological date are hard and dense rocks and must be ground before use. Such are the fire-clays immediately beneath Carboniferous coal-seams. Clays are blue, red and brown according to the state of the iron oxide, whether ferrous or ferric, or they may be nearly white when it fails. The less pure brick clays as shown by the analyses contain oxides of iron, calcium, magnesium and of the alkalies in quantity, but fire-clays practically lack these.

As contrasted with the transported or sedimentary clays just mentioned, there are residual clays that result from the decay of impure limestones and that are found on weathered outcrops. They are very impure and variable in composition, but they are markedly plastic.

Metamorphism. — In metamorphic processes shales become compacted and oftentimes silicified. Their lack of homogeneity causes them to yield irregularly breaking and very tough rocks called graywackes, which differ only in greater hardness from their unaltered originals. Excessively silicified shales are called phthanites and are important in the Coast Range of California. Shales also under shearing stresses and attendant mineralogical reorganization pass into schists of various kinds, such as quartz-schist, mica-schist and possibly hornblende-schist. G. F. Becker even mentions rocks derived from them that are mineralogically like diabases and diorites, but their recognition is a matter for microscopic study. Clays under shearing stresses develop new cleavages without regard to their original bedding and from the homogeneous character of the original and the perfection of the cleavage, slates result, which are of great practical importance.

Occurrence. — Shales and clays are such common members of extended geological sections as to deserve no special mention. They are often a thousand feet or more in thickness and cover great areas.

CALCAREOUS SANDSTONES, MARLS.

	SiO_2	Al_2O_3	FeO Fe_2O_3	CaO	MgO	K_2O	Na_2O	CO_2	H_2O or Loss.
Calc. Sandst.									
1.	79.19	3.75		7.76	3.20	...	...		3.26
2.	38.41	5.77	1.79	20.08	8.82	0.12	0.29		
Calc. Shales.									
3.	39.70	26.83		19.28	2.43	5.11			
4.	28.35	12.37		21.47	8.24	5.73			
Marls.									
5.	43.70	25.00		8.85	2.33	...	...	5.40	9.21
6.	38.70	10.20	18.63	9.07	1.50	3.65	...	6.14	10.00
7.	28.78	11.63	2.96	24.50	2.91	2.12	...	22.66	4.18

1. Calcareous sandstone, Flagstaff, Ariz. Quoted by G. P. Merrill, Stones for Building and Decoration, 420. 2. Calcareous sandstone, Jordan, Minn., *Idem.* 3. Genesee Shale, Mt. Morris, N. Y., supplied by H. Ries. 4. Niagara Shale, Rochester, N. Y., H. T. Vulté, analyst. Supplied by H. Ries. 5. Cretaceous Marl, Hop Brook, N. J., Geol. of N. J., 1868, 419; also P_2O_5, 2.18. 6. Cretaceous Marl, Red Bank, N. J., *Idem*, 418; also P_2O_5, 1.14, SO_3 0.14. 7. Subcarboniferous marl, Bowling Green, Ky., Ky. Geol. Surv., Chem. Analyses A, Part 3, 90; also, P_2O_5, 0.25.

Comments on the Analyses. — The analyses illustrate in a very suggestive way the passage of these mechanical sediments into impure limestones. The gradual intermingling of more and more of shells and other remains of organisms brings it about. The high P_2O_5 of the marls, as cited under the references, is worthy of remark. It is to be appreciated that the lime and magnesia and some of the iron of the analyses are to be combined with CO_2, even though the CO_2 is not mentioned.

Mineralogical Composition, Varieties. — Calcareous sandstones are practically sandstones with rich calcareous cement, or with a large amount of organic fragments intermingled with the prevailing quartz sand. They are passage forms to the fragmental limestones. Calcareous shales derive their lime partly from the fine organic sediment that is deposited with the siliceous and aluminous particles and partly from contained fossils. Beds of these rocks are particularly favorable layers for the discovery of the latter, and often break the monotonous barrenness of a geological section composed of ordinary shales. Marls, strictly speaking, are calcareous clays, and originate in typical cases by the deposit of limy slimes along with the aluminous. The lime destroys the plasticity of the clay and yields a crumbling rock, often richly provided with fossils and of value as a fertilizer. Grains of glauconite, the green silicate of potash and iron, are at times present, and characterize the so-called

"green sands" which are valuable as fertilizers. The term marl is somewhat loosely used in its applications, and moderately coarse calcareous sands, and even beds which show but small percentages of lime on analysis are designated by it in the States along the Atlantic seaboard from New York south. It is clear that marls are intermediate rocks between clays and impure earthy limestones.

Metamorphism. — The rocks of this group are altered in metamorphic processes to schistose forms, not so essentially different from those resulting from the common aluminous shales and clays, except that the richness in lime facilitates the production of minerals requiring it. The marls, when high in lime, behave like impure limestones, and are prolific sources of silicates. Marls are, however, much more common in later and unmetamorphosed formations than in older ones, although it may be that in the latter they have yielded some schistose derivatives not readily traceable back to them.

Occurrence. — Calcareous sandstones and shales are met as occasional beds in series of the more abundant, distinctively aluminous varieties. Marls are chiefly developed in the Cretaceous and Tertiary strata of the Atlantic seaboard and around the Gulf of Mexico. Freshwater ones are not lacking in the Tertiary lake basins of the West.

CHAPTER VIII.

Limestones; Organic Remains not Limestones; Rocks Precipitated from Solution. Determination of the Aqueous and Eolian Rocks.

II. Limestones.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	CO_2	H_2O	Insol.	$CaCO_3$	$MgCO_3$
Living Organisms.											
1. (Coral)					54.57			2.54		97.46	
2. (Reef-rock)					53.82	1.01				96.11	2.13
3. (Lagoon Sed.)					54.58	0.85				97.47	1.79
4. (Coral)					44.96	3.87				80.29	8.14
5. (Oyster Shells)					44.4	1.3	35.4	14.5		(79.28)	(2.73)
Calcite.											
6. Pure Mineral.					56.		44.			100.	
Dolomite.											
7. Pure Mineral.					30.43	21.72				54.35	45.65
Marine Limestones.											
8.	0.63		0.55		55.6	0.23				99.30	0.49
9.			1.06		53.78	0.34		0.90	1.13	96.04	0.72
10.				1.25	53.89	0.10				96.24	0.21
11.	1.84	0.64		1.82	51.40	2.23	41.19	0.27		91.80	4.68
12.	12.34		7.00		44.41	0.44				79.30	0.92
13.	3.77	0.08		6.80	33.79	15.32	42.21			60.35	32.61
14.			0.55		29.54	21.08		1.82	0.60	52.75	44.28
Waterlime.											
15.	18.34		7.49		37.60	1.48		3.94		67.14	2.90
16.	15.37		11.38		25.70	12.44		1.20		45.91	26.14
Siliceous.											
17.			1.20		17.69	10.59		1.24	43.72	31.60	22.24
Freshwater Limestone.											
18.				0.37	54.16	0.15	43.68		1.49	96.71	0.31
19.		1.83		0.22	34.20	0.11	26.79	4.64	31.28	61.07	0.23
Travertine.											
20.	0.08		0.15		53.83	0.90	41.79	1.43		94.97	0.43

1. Stag's horn coral (*Millepora alcicornis*), S. P. Sharpless, Amer. Jour. Sci., Feb., 1871, 168. 2. Bermuda coral reef rock. A. G. Högbom, Neues Jahrb., 1894, I., 269. 3. Bermuda coarse lagoon sediment, *Idem*. 4. Average of 14 analyses of the coral *Lithothamnium* from localities the world over, *Idem*, 272. 5. Oyster shells, Geol. of New Jersey, 1868, 405. 6. Calculated from $CaCO_3$. 7. Calculated from $CaCO_3$ $MgCO_3$. 8. Crystalline Siluro-Camb. limestone, Adams, Mass., E. E. Olcott for Marble Co. 9. Limestone, Bedford limestone, Ind. Quoted by T. C. Hopkins, Mineral Industry, 1894, 505. 10. Solenhofen lithographic stone. Quoted by G. P. Merrill,

Stones for Building and Decoration, 415. 11. Limestone, Hudson, N. Y., Th. Egleston. 12. Trenton limestone, Point Pleasant, Ohio, vide No. 10. 13. Surface Rock, Bonne Terre, Mo., J. T. Monell, unpublished. 14. Limestone, Chicago, T. C. Hopkins, Mineral Industry, 1895, 508. 15. Hydraulic limestone, Coplay, Penn. Quoted by W. A. Smith, Mineral Industry, 1893, 49. 16. Hydraulic limestone, Rosendale, N. Y., *Idem.* 17. Siliceous limestone, Chicago, Ill., vide No. 14. 18. Miocene limestone, Chalk Bluffs, Wyo., R. W. Woodward, 40th Parallel Surv., I., 542. 19. Eocene limestone, Henry's Forks, Wyo., B. E. Brewster, *Idem.* 20. Travertine, below Hotel Terrace, Yellowstone Park, J. E. Whitfield, for W. H. Weed, 9th Ann. Rep. Dir. U. S. Geol. Surv., 646.

Comments on the Analyses. — The first three analyses and the fifth indicate that the calcareous parts of living organisms are quite pure calcium carbonate. The fourth analysis is of that species of coral which, so far as we know, is highest in magnesia. Small amounts of calcium phosphate are often present as well, some shells being richer than others. Nos. 6 and 7 are introduced so as to give a basis for estimating the purity of the following limestones: Nos. 8, 9 and 10 are extremely pure varieties, and from these, as a starting point, the other components increase in one analysis and another. No. 14 is a nearly typical dolomite. Nos. 12 and 17 are highly siliceous, and Nos. 15 and 16 are both strongly argillaceous. The last two are closely parallel in composition with marine varieties. An analysis of a travertine is given in No. 20.

It at once appears that Nos. 13, 14, 16 and 17 are far higher in magnesia than any known living organism, and it is evident that an original organic deposit must have undergone an enrichment in magnesium carbonate to bring them about. Dana suggested many years ago that coral or other organic sand, when agitated in sea-water, probably exchanges a part of its calcium for magnesium, and there is much reason to think that it does. Otherwise, the change must have been brought about by magnesian solutions percolating through the rock and altering it by the replacement process called dolomitization, or dolomization. Much of the silica, no doubt, results from radiolarians and sponge spicules, but much also, together with the alumina, from fine fragmental sediments.

Origin. — Much the greater number of the important limestones are of marine origin, but in certain geological formations fresh-water ones are well developed. The calcareous remains of organisms have been their principal source, and of these the foraminifera, the corals, and the molluscs have been the chief contributors.

Their shells have often become thoroughly comminuted to a calcareous slime before final deposition, so that the resulting rock affords no trace of organic structure. The solubility of the carbonate of lime aids in the cementation of the slime to rock and tends to efface the organic characters. Limestones pass by insensible gradations through more and more impure varieties into calcareous shales and marls, but, as a rule, they are deposited in deeper water than the true shales and sandstones. This conception must not be applied too strictly, because, beyond question, a depth of a few feet has often sufficed, and too much emphasis has often been placed upon the depth regarded as necessary for limestones. Coral sands accumulate on or near the immediate shore, and may even be heaped up by the wind.

The general geological relations involved in the deposition of limestones are well illustrated in the accompanying Fig. 41. The

FIG. 41. Cross-section of a fossil-coral reef at Alpena, Mich., showing the reef-coral in the fan-shaped pattern; the coarse coral-sand in the shaded part; and the fine sand shading into slimes farther away. After A. W. Grabau, Annual Rept. Mich. State Geologist, 1901, 176.

reef of coral grows constantly and from the action of the breaking waves is partially comminuted to sand, which settles on the flanks and furnishes a place of residence for various mollusca whose hard parts contribute also to the growing limestone. The finer material is transported to a greater distance and gradually settles out as slimes which afford dense and often thin-bedded varieties. The conditions for the deposition of the latter have often been unfavorable for organic life, and it frequently happens that the resulting limestones are devoid of fossils except in the vicinity of the old reef. Based upon the varieties just outlined, A. W. Grabau has suggested the following varieties of limestones; organic limestones, such as would be afforded by the reef itself; coarse, clastic limestones or calci-rudites (*i. e.*, lime-rubbles); sand limestones or calcarenites (*i. e.*,

lime-sands); and mud limestones or calcilutites (*i. e.*, lime-muds) (Bulletin Geol. Soc. Amer., XIV., 348–352.)

In confined estuaries of sea water subjected to evaporation, enough carbonate of lime is precipitated directly from solution, to yield important strata, which are often met in a series of beds associated with rock salt and other precipitated rocks as later set forth. Calcareous deposits from limy springs may also almost reach the dignity of rocks, and when abundant are called travertine or calcareous tufa. If particles of dust, etc., are suspended in limy springs or in concentrated estuarine waters, they gather concentric shells of the carbonate and may yield oölitic deposits from the coalescence of the concretions. Some algæ likewise secrete oölitic calcite and contribute extensively to rocks.

Mineral Composition, Varieties. — Calcite is the chief mineral of limestones, and when thin sections are magnified it exhibits its characteristic cleavages. Dolomite and siderite accompany it frequently, and their molecules also replace the calcium carbonate, in a greater or less degree, so as to form double carbonates. An unbroken series can readily be traced from pure calcium carbonate, through more and more magnesian forms, to true dolomite. Those with over 5 per cent. MgO are usually described as magnesian limestone, and when the MgO mounts well toward the 21.72 per cent. in the mineral dolomite, we use the latter name. In the same way, a series of ferruginous varieties may be established toward the clay ironstone and black band ores, and a siliceous series toward the flints and cherts. Cherty limestones are a very common variety, and are referred to again in connection with chert. When the argillaceous or clayey intermixtures enter, argillaceous or hydraulic varieties result that are generally drab and close-grained, and are useful in the manufacture of cement. Bituminous matter may be present, making the limestones black, and this, in the form of asphalt, may yield asphaltic varieties.

Besides these varieties established on the basis of chemical composition, special names may be given because of structure. Thus earthy limestones tend to crumble to dirt; oölitic limestones resemble the roe of a fish; pisolitic varieties consist of concretions of size comparable with peas; and other terms are employed, that are self-explanatory. Prominent fossils suggest names, such as

crinoidal, from fossil crinoids; coraline, foraminiferal and many more of local or stratigraphic significance. Practical applications play a part in nomenclature, supplying "waterlime," "cement-rock," "lithographic limestones," etc.

Metamorphism. — Limestones feel the effect of metamorphism with exceptional readiness and under deforming stresses, probably accompanied by elevation of temperature, and in the presence of water, or along the contacts with intruded dikes and sheets of igneous rocks, they lose their sedimentary characteristics, such as bedding-planes and fossils, and change into crystalline marbles. The contained bituminous matter becomes graphite; the alumina and silica unite with the lime, magnesia and iron to give various silicates. Other oxides together with the bituminous ingredients contribute to the various colorations. Mechanical effects are manifested in flow lines, brecciation and other familiar features of many that are cut and polished for ornamental stones. Impure limestones which undergo these metamorphic changes are the most prolific of all rocks in variety and beauty of minerals. Arendal, Norway, and the crystalline limestone belt from Sparta, N. J., north through Franklin Furnace are good illustrations. The crystalline limestones will be again mentioned under the metamorphic rocks.

Occurrence. — Limestones are too common to deserve special mention as regards occurrence. They are frequently met in all parts of the country, but the Trenton limestone of the Ordovician, the Niagara of the Silurian and the Subcarboniferous limestones of the Mississippi Valley are specially worthy of note.

III. Remains of Organisms not Limestones.

Calcareous remains are much the most important of the contributions made by organisms to rocks, but there are others, respectively siliceous, ferruginous and carbonaceous, which deserve mention.

Siliceous Organic Rocks.

The principal members of this group are infusorial or diatomaceous earths; siliceous sinters; and cherts, hornstones or flints, the three last names being practically synonymous. Infusorial earths consist of the abandoned frustules of diatoms, which are micro-

scopic organisms belonging to the vegetable kingdom. Though not a common rock, they yet are met in series of sedimentary strata, both freshwater and marine, with sufficient frequency to justify their mention. Some foreign earthy materials are unavoidably deposited with them. The siliceous sinters are extracted from hot springs by algæ which, as shown by W. H. Weed, are capable of living and secreting silica in waters up to 185° F. They are far less important geologically than the infusorial earths. Chert is a rock consisting of chalcedonic and opaline silica, one or both. It possesses homogeneous texture and is usually associated with limestones, either as entire beds, or as isolated, included masses. It often has druses of quartz crystals in cavities, and in thin sections under the microscope it sometimes exhibits sponge spicules. Cherts not provided with these organic remains may be regarded with great reason as chemical precipitates, and as American varieties in the great majority of cases lack them the cherts receive more extended mention under the chemical precipitates.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	H_2O
Infus. Earths.									
1.	91.43	2.89		0.66	0.36	0.25	0.63	0.32	3.8
2.	86.90	4.09		1.26	0.14	0.51	0.77	0.41	5.99
3.	75.86	9.88	2.92		0.29	0.69	0.08	0.02	8.37
Silic. Sinter.									
4.	89.54	2.12		tr.	1.71	tr.	1.12	0.30	5.13
Chert.					$CaCO_3$.	$MgCO_3$.			
5.	34.0	0.80			63.4	1.5	0.3		

1. Miocene, Little Truckee River, Nev., R. W. Woodward, 40th Parallel Survey, I., opposite p. 542. 2. Fossil Hill, Nev., *Idem.* 3. Richmond, Va., M. J. Cabell, Mineral Resources, 1883–84, p. 721. 4. Deposit from Old Faithful, Yellowstone Park, J. E. Whitfield, for W. H. Weed, 9th Ann. Rep. Dir. U. S. Geol. Sur., 670. 5. Cretaceous chert, England, Jukes-Brown and Hill, Quar. Jour. Geol. Soc., Aug., 1889.

Comments on the Analyses. — The infusorial earths are fairly high in water, and this is the main cause of low silica, but, as stated above, their growth and accumulation in water make it unavoidable that more or less clay and other sediments should mingle with them. In these and the other members of the series, it is important to understand that much of the silica is opaline, or amorphous, hydrated silica, and not quartz or chalcedony. Tests of the amounts soluble and insoluble in caustic alkali are usually made to determine the proportions of the two, for, while it is not

an accurate separation — quartz and chalcedony being themselves somewhat soluble—it gives an approximate idea. No. 4 is a deposit separated from the geysers by algæ and evaporation. No. 5 is largely due to sponge spicules, mixed in with chalk, and therefore is high in calcic carbonate.

Mineralogical Composition, Varieties. — The mineralogy of the infusorial earths can be stated less definitely than the chemical composition. The individual diatoms are very minute, but the analyses indicate both opaline and chalcedonic silica as being present. In the sinters and cherts, when the latter can be shown to be organic, the same two varieties are recognizable, and with them are varying amounts of calcite. The infusorial earths are fine, powdery deposits, resembling white or gray, dried clays, but they lack plasticity and are best recognized with the microscope. Siliceous sinters, often called geyserite, are cellular crusts and fancifully shaped masses that closely resemble calcareous tufas, but that are readily distinguished by their lack of effervescence. Chert is dense, hard and homogeneous, and of white, gray or black color. It readily strikes fire with steel, and when it breaks has a splintery or conchoidal fracture. It is often decomposed to powdery silica on the outside, and in extreme cases may yield rather large deposits of this powder, which are called "tripoli," and are used for various practical purposes. Mention may again be made of the cherts that seem best explained by chemical precipitation.

Metamorphism. — The cherts alone of these rocks are of sufficient importance to attract attention in this connection, and their metamorphism is briefly referred to on page 117.

Occurrence.— Infusorial earths are abundant near Richmond, Va., and on Chesapeake Bay, at Dunkirk, and Pope's Mills, Md. Beds deposited in evanescent ponds or lakes are also well known in States farther north. In the West, the Tertiary strata have yielded them in Nevada. In California and Oregon great areas are reported by Diller. Siliceous sinters produced by algæ are quite extensive in the Yellowstone Park, and similar deposits, perhaps caused by the same agent, are found in many regions of hot springs. Sinters chemically precipitated also occur. The most important occurrences of chert are all mentioned together on page 118.

Ferruginous Organic Rocks.

It is a question whether these deserve the dignity of rocks, for they may with great propriety be classed with the minerals, distinctively so called. It will therefore only be mentioned that many have attributed the formation of beds of limonite to the separation of iron hydroxide by low forms of organisms. Even granting this, it is still true that such limonites are insignificant when compared with those that result by purely inorganic reactions in the decay of rocks. Important strata of cherty carbonates of iron are present in the iron mining districts around Lake Superior and have been, no doubt, the principal source of the hematites. Van Hise regards them as probably of organic origin, but the evidence is not decisive and they may be chemical precipitates. Clay-ironstone and black-band ores — that is, argillaceous and bituminous ferrous carbonate — sometimes form continuous beds instead of the usual isolated lenses, but when they do, they are not organic in origin, although decaying organic matter may be instrumental in preserving the reducing conditions that are necessary to the formation of the ferrous salt.

Carbonaceous Organic Rocks.

When plant tissue accumulates in damp places and under a protecting layer of water which prevents too rapid oxidation, new accessions may more than compensate for loss by decay so that extensive deposits may result. These become progressively rich in carbon by the loss of their other elements and yield beds of considerable geological, but much greater practical importance. The course of the changes and the several stages are indicated in the following table:

	C.	H.	O.	N.	Total.
Woody Tissue	50	6	43	1	100
Peat	59	6	33	2	100
Lignite	69	5.5	25	0.8	100.3
Bituminous Coal	82	5	13	0.8	100.8
Anthracite	95	2.5	2.5	trace.	100

The changes are in the nature of loss of oxygen and hydrogen, and also of carbon, but the decrease of the first two is relatively so much greater, that the carbon actually is enriched. The table is theoretical in that no account is taken of the more or less fortuitous

mineral matter which forms the ash together with a small percentage of incombustibles in the vegetable tissue itself. Peat is a more or less incoherent mass of twigs and stems, decidedly carbonized and darkened, but with the original structures, as a general rule, still well preserved and recognizable. By gradual stages it passes into lignite, which is still further compacted, and which exhibits the original structures more faintly. In bituminous coal, they are seldom recognizable, and the aggregate is compact and black. In anthracite the coal is dense, amorphous and lustrous. The oxidation necessary to the later varieties may have been largely performed before actual burial in other rocks, but the changes are continuous and progressive in all.

Other organic derivatives, such as asphalt, petroleum, etc., are not considered to be of sufficient abundance to rate as rocks.

Metamorphism. — Anthracite is locally produced from bituminous coal near igneous intrusions, and by regional metamorphism, as later explained. The chemical changes are the same as those progressive ones above outlined, but are doubtless more rapidly brought about. Anthracites become graphitic, and, as a theoretical extreme, pass into graphite. Natural cokes are also produced along intruded dikes.

Occurrence. — Peat favors cool and moist latitudes in all parts of the world, and is chiefly of fresh water origin. Lignites and coals are best developed in the Carboniferous and Cretaceous strata, and where the former occur in the East and the latter in the West, they often contain coal seams.

IV. Precipitates from Solution.

The name of this group indicates the character of the rocks that comprise it. Bearing in mind the condition established at the outset, p. 1, that a rock should form an essential part of the earth, it is evident that water is the only natural solvent abundant enough to yield such rocks, and that only the most widespread compounds which are notably soluble in it, or in its common solutions of other more soluble salts, can meet this requirement. The rocks may be conveniently taken up under the following heads. 1. Precipitates involving the alkaline earths and alkalies. 2. Siliceous precipitates. 3. Ferruginous precipitates.

PRECIPITATES INVOLVING THE ALKALINE EARTHS AND ALKALIES.

The carbonate of lime in stalactites, stalagmites and crusts on the walls and floors of caves in limestone or in the surface deposits from limy springs, affords a rock of this character. It is a form of limestone, from pure varieties of which it does not differ in composition, although its banded structure and rings of growth, which we may describe by Posepny's useful word "crustification," in a measure distinguish it. Naturally such deposits are often beautifully crystalline, free from admixture except of associated dissolved materials and as a rule purer than sedimentary limestones. They yield our well-known onyx marbles. Some regularly stratified deposits of limestones that are associated with the precipitated rocks next discussed have doubtless originated together with the latter.

Gypsum and rock salt are the chief members of this subgroup. They occur quite invariably in association, and have resulted alike from the evaporation of sea-water and from the drying up of lakes, originally fresh. Both are mixed more or less with dust and other mechanical sediments washed or blown into the evaporating reservoir, or are interbedded with other salts which were present in a minor capacity in the mother liquor, but instances of thick beds, especially of rock salt of surprising purity, are well known. When these attain several hundred or even a thousand feet, it is evident that more than twenty-five times this depth of salt water, on the basis of the known composition of the sea, would have to be evaporated, and this is a practical absurdity for any conceivable confined body, even with occasional renewals from breaches of the barrier. It would be necessary to assume wide stretches of shallows which were practically evaporated to dryness, while at the same time subsidence of the coast was progressing at just about the necessary rate to keep pace with the growth of the salt. The recent explanation, however, advanced as the "Bar theory," by Ochsenius,* clears it up. We need only to assume a relatively deep and nearly land-locked estuary, with a shallow bar between it and the sea. Evaporation continually concentrates the confined salt water and especially the portion on the shallow bar. This, becoming rich in mineral matter and of high specific gravity, flows inward and

* *Zeitschrift f. Praktische Geologie*, May and June, 1893. An excellent abstract by L. L. Hubbard appears in the Geol. of Michigan, V., Part II., p. ix.

down the slope of the bar to the bottom of the estuary. In the course of time, and allowing for the influence of pressure in the depths and of temperature, conditions favorable to precipitation, first, of the insoluble gypsum, later of the more soluble common salt will be reached, and in varying and alternating layers they will be built up indefinitely, or until some upheaval or subsidence alters the relations of the estuary to the sea. More or less anhydrite is also deposited, and is later found in extended cross-sections of salt-bearing strata. The most soluble ingredients, such as KCl, $MgCl_2$, $MgSO_4$, etc., become continually richer in the mother liquor, and unless this is also finally evaporated, they escape and are not found in the series. So far as we know, the Stassfurt district, in Germany, is almost the only place where this escape has been prevented on a large scale, although rock salt is of world-wide distribution.

Gypsum forms at times gray or black earthy beds, that look very much like limestone, but of course do not effervesce. Again, it is in white, cream-colored or more deeply tinted layers, yielding alabaster. Minor portions are in condition of selenite, the clear, transparent variety, and thin coats of native sulphur are seldom lacking. Rock salt forms crystalline beds, often stained red or brown, by iron oxide. Both gypsum and salt may impregnate associated sediments more or less, yielding gypseous or saline shales and marls. In many localities gypsum deposits have undergone a complex series of chemical changes in the general nature of deoxidation from carbonaceous matter present, so as to yield native sulphur in large amounts.

Metamorphism. — None of the above rocks are worthy of mention as regards metamorphism.

Occurrence. — In America, gypsum is found especially in the Upper Silurian of New York; the Lower Carboniferous of Michigan and Nova Scotia; the Triassic in the states of the Great Plains such as Kansas and Texas; in undetermined Mesozoic in Iowa; and in the Jura-Trias or in undetermined strata in Colorado, Utah and the West. Rock salt occurs in the Upper Silurian of southern New York; in the Triassic of Kansas; in the Quaternary (?) of Petite Anse, La., and at many places of recent geological age in the West.

Siliceous Precipitates.

	(a)SiO_2	(b)SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	H_2O or Loss.	Sp. Gr.
Geyserite.										
1.	81.95		6.49	tr.	0.56	0.15	0.65	2.56	7.50	
Cherts.										
2.	99.46		0.29		0.4	tr.			0.34	
3.	3.35	95.78	0.16		tr.	0.01			0.20	
4.	4.52	93.65	0.83		0.05	0.01			0.78	
5.	98.10		0.24	0.27	0.18			0.23	1.16	
6.	94.91		2.85		0.42	tr.				
Sil. Oölite.										
7.	95.83		2.03		1.93	tr.				2.63
					$CaCO_3$	$MgCO_3$				
8.	56.50		1.50		16.84	2.60			12.54	2.688
9.	3.70		1.42		88.71	8.09				2.654
Cherty iron carbonates.					CaO	MgO	FeO	MnO		CO_2
10.	58.23		0.06	5.01	0.38	9.59	18.41	0.25	2.08	5.22
11.	46.46		0.24	0.64	1.87	3.10	26.28	0.21	1.22	19.96
12.	28.86		1.29	1.01	0.74	3.64	37.37	0.97	0.68	25.21

Note. (a) SiO_2 means silica soluble in caustic alkali; (b) SiO_2 silica insoluble in the same.

1. Geyserite, Splendid Geyser, Yellowstone Park, J. E. Whitfield for W. H. Weed, 9th Ann. Rep. U. S. Geol. Sur., 670. 2. Gray unaltered chert, Joplin, Mo. Analysis made by U. S. Geol. Surv. Quoted in Ann. Rep. Geol. Sur. Ark., 1896, III., 161. 3. White altered chert, Galena, Kan., *Idem.* 4. Unaltered chert, Bellville, Mo., *Idem.* 5. Decomposed chert, or Tripoli, Seneca, Mo., W. H. Seamon. Quoted by E. O. Hovey, Amer. Jour. Sci., Nov., 1894, 406. 6. Chert, Roaring Springs, Newton Co., Mo., J. D. Robertson, for E. O. Hovey, *Idem.* 7. Siliceous oölite, Center Co., Penn., Barbour and Torrey, Amer. Jour. Sci., Sept., 1890, 249. 8. Silica-lime oölite, *Idem.* 9. Lime-silica oölite on same specimen as No. 8, *Idem.* 10, 11. Cherty iron carbonates, N. E. Minn., T. M. Chatard, for C. R. Van Hise, Monograph XIX., U. S. Geol. Survey, 192. 12. Cherty iron carbonate, Sunday Lake, Gogebic Range, Mich., W. F. Hillebrand, *Idem.*

Comments on the Analyses. — The first seven are high in silica, some approximating chemical purity. No. 1 has admixtures of mud thrown out by the geyser from its walls. The five cherts, 2–6 inclusive, have but slight amounts of alumina, iron and lime, and low percentages of water. Nos. 3 and 4, by the determinations of soluble silica give us some idea of the amount of the opaline form that is present. The three analyses 7, 8 and 9 are a most instructive series, passing as they do from nearly pure silica into a moderately siliceous, magnesian limestone, from which the first two are thought to have been derived by replacement. Nos. 10, 11 and 12 are the curious cherty carbonates of iron from which

the Lake Superior iron ores have been formed by subaërial decay. Their richness in magnesia as compared with lime is noteworthy.

Mineralogical Composition, Varieties. — Cherts are so exceedingly fine grained that they give no indication of their constituent minerals to the unaided eye. The microscope shows, however, that they are chiefly chalcedony in excessively minute crystals, with which are associated varying amounts of opaline silica, quartz crystals, calcite or dolomite rhombs and dusty particles of iron oxide. In foreign cherts as stated above on p. 102, sponge spicules have been met, but not in the important American varieties. Cherts often have an outer powdery crust, due to alteration, and while as shown by analysis 5, this may not mean any notable chemical change, it may penetrate whole beds and leave only a white, incoherent mass called "tripoli," that is used for a polishing powder and for various other purposes. Cherts have spherulites occasionally and are still more often oölitic. The cherty or siliceous rocks of the formations containing the Lake Superior iron ores are mixtures of chalcedonic silica and carbonate of iron in varying proportions, and in their alteration they afford more or less sharply differentiated jaspers and hematites. Three analyses of varying composition are given above, Nos. 10, 11 and 12. Cherts vary in color from black through gray to creamy white.

As stated earlier, cherts are intermingled in all proportions with limestones. They are very puzzling problems as regards origin. Where devoid of organisms, the majority of observers regard them as in some way precipitated chemically from sea water, possibly as gelatinous silica. They may also result by replacement of limestone. Their structure and relations give us few definite clues on which to base a firm conclusion. As earlier stated, others regard them as derived from siliceous remains of organisms, such as sponges, radiolarians and the like, which may have been redissolved and worked over into chalcedony, making them practically precipitates. Cherts are also called hornstone and flint.

Metamorphism. — Purely siliceous cherts are unpromising subjects for metamorphism, except as they yield silica for the production of silicates from cherty limestones. The ferruginous cherts of Lake Superior pass into actinolitic and magnetitic slates, a most interesting change, especially in the former case. The lime mag-

nesia and iron are combined with silica under the metamorphosing influences so as to yield the variety of actinolite called grünerite.

Occurrence. — The abundance of cherts or related rocks in the region of Lake Superior, either associated with limestone or in the cherty carbonates described above, is remarkable. In their economic products, they are the most important strata present. The Siluro-Cambrian limestones are often cherty both east and west, and in the New York and Ohio Devonian, the so-called "Corniferous" limestone was named from its richness in "hornstone." In the Mississippi Valley the lower Carboniferous strata are particularly prolific in cherts. Fractured cherts are the chief gangue of the zinc ores of southwest Missouri.

Ferruginous Precipitates.

Some iron ores doubtless originate in this way, and the processes by which the soluble proto-salts are oxidized and precipitated as the insoluble ferric hydroxide are well understood. But they may be considered rather as minerals than as rocks. The cherty iron carbonates of the preceding section have already been cited, and the clay ironstones and black-band iron ores are omitted from further mention for the same reasons as are the limonites.

The Determination of the Aqueous and Eolian Rocks.

The members of this series are much easier to recognize than are the igneous. Breccias, conglomerates and sandstones are at once apparent from their fragmental character. Breccias differ from conglomerates in the angular shape of their component fragments. As the sandstones become finer, the argillaceous varieties may be distinguished by the peculiar odors emitted by all clays and clayey rocks when breathed upon. The calcareous sandstones and marls betray themselves by effervescence with acid. All limestones, unless too rich in magnesia, effervesce in cold acid, and the more readily if first scraped up into a little heap of powder with a knife. Dolomites effervesce much less readily, and warm acid may be necessary. Infusorial earth may need the microscope for its certain identification, and then the abundance of the little organisms is very apparent. The cherts are so characteristic in appearance as to admit of little uncertainty, except as compared with the silici-

fied tuffs and excessively fine felsites, called petrosilex, in which case geological surroundings or the microscope are the only resources. The ferruginous rocks, if such be allowed, are self-evident, as are the carbonaceous. Gypsum is easily recognized when in the crystalline form, but when black and earthy, the observer may be forced to determine its lack of effervescence, and to make a sulphur test with the blowpipe. Nevertheless with these rocks as with the igneous, although to a less degree, it is very advisable to gain experience with correctly labeled study collections or with the systematic exhibits of a museum, so that the student may have a fund of personal observation back of him from which to draw, and on which to depend when a rock comes up for determination.

For field work and travel, it is well to appreciate that a few dry crystals of citric acid, that can be dissolved in a little water as needed, serve very well for tests of effervescence. They are more safely carried than are liquid mineral acids.

Table of Classification.

On p. 120 a summarized table of classification of the breccias and the sedimentary rocks proper is given which will present a birds-eye-view of the varieties just described. It may be compared with the similar one of the metamorphic rocks on p. 160 since so many of the latter are derived from the sediments.

Breccias.		Sedimentary Rocks.							
		Fragmentals not Limestones.		Transition to Limestone.	Limestones.		Organic Rocks not Limestones.		Precipitates from Solution.
		Loose.	Consolidated.	Consolidated.	Loose.	Consolidated.			
Fault-Breccias.	Coarse.	Gravel.	Conglomerate.	Calcareous Conglomerate.	Limestone-Rubble. Gravel. Coral heads, etc.	Rubble-Limestone. Calcirudites.	Alkaline.		Rock salt—gypsum, stalactites, stalagmites, "Mexican onyx" — travertine.
Talus-Breccias.	Fine to Medium.	Sands.	Sandstone.	Calcareous Sandstone.	Shell or coral sands.	Sand limestones. Coquina. Calcarenites.	Siliceous.	Infusorial or diatomaceous earth. Some cherts. Some sinters.	Silicified wood. Some cherts. Some sinters.
Eruptive-Breccias.		Mud.	Argillaceous Sandstone. Shale.	Calcareous Shale.	Shell or coral muds.	Mud limestones. Calcilutites.	Ferruginous.	Some limonite.	Some limonite.
		Silt.	Clay.	Marl.	Calcareous slimes or ooze.	Lithographic limestone.	Carbonaceous.	Peat. Lignite. Bituminous coal. Anthracite.	Asphaltites.

CHAPTER IX.

The Metamorphic Rocks. Introduction. The Rocks Produced by Contact Metamorphism.

The word metamorphism was first introduced into geological literature by Lyell in 1832, and was used to describe the processes by which rocks undergo alteration. It was particularly applied by him to those stratified rocks that, from deep burial in the earth, and from the consequent heat and pressure to which they have been subjected, have assumed structures and textures resembling those of the unstratified primary or plutonic. In this sense it has been generally employed since, and it implies an increase in crystallization, hardness and those attributes, which are especially associated with the crystalline schists, as contrasted with the unaltered sediments.

The literal meaning of the phrase "the processes by which rocks undergo alteration" may, nevertheless, be somewhat more comprehensive than this, and may be made to include the changes produced by atmospheric agents, which we ordinarily describe by the term weathering, and in the following pages the products of this latter form of alteration will be briefly considered as a third and concluding group.

The metamorphic rocks will therefore be taken up under the following three classes:

I. Rocks reduced by Contact Metamorphism.
II. Rocks produced by Regional Metamorphism.
III. Rocks produced by Atmospheric Weathering.

By contact metamorphism is meant the series of changes that are effected by an igneous intrusion, such as a dike or a laccolith upon the rocks through which it is intruded. These changes are often profound, and are brought about by the heat of the intrusion as well as by vapors and hot solutions which it may likewise give forth. The wall-rock may be itself igneous or sedimentary, or even metamorphic. This form of metamorphism is sometimes called "local" as contrasted with "regional."

By regional metamorphism we describe the series of changes which are produced in the rocks of wide areas or "regions" by deep burial, mountain-making upheavals, and by heat and pressure. Although Lyell had stratified rocks before him as the chief materials on which these agents acted, yet it is well recognized today that igneous rocks are no less profoundly affected, and indeed that the results of their alteration may be almost or quite indistinguishable from those derived from sediments. But there is great uncertainty as to the original condition of many regionally metamorphosed rocks, and although the endeavor has been made in previous pages to throw as much light on them as possible, by systematically referring to the alteration and metamorphism of simple types, nevertheless, many are obscure, and in their history are involved some of the profoundest problems of geology.

By atmospheric weathering is meant the series of changes wrought in rocks at or near the surface of the earth, by the ordinary atmospheric agents, water, oxygen, carbonic acid and the like. The changes are chiefly in the nature of disintegration, loss of soluble ingredients and decomposition, and in general they produce a marked shrinkage of bulk.

It is important to appreciate that under whatever form the metamorphic rocks are met, they are of necessity alteration products of the two grand divisions over which we have already passed.

Generalities Regarding Contact Metamorphism.

Widening observation has shown that contact metamorphism is produced by all varieties of igneous rocks and that it may be broadly stated to be independent of the kind of rock forming the intrusion. Granites, syenites, nephelite-syenites, diorites, gabbros and even peridotites have in one place and another proved to be efficient agents. Yet the following statements may be said to hold good.

1. Plutonic rocks are more favorable to it than volcanic. This follows because plutonic rocks cool slowly at considerable depths and stand therefore at high temperatures for long periods next their walls.

2. Magmas rich in mineralizers are much more favorable than are those poor in them. This naturally follows from the powerful

influence exerted by escaping vapors. It is tantamount to saying that acidic rocks are in general more efficient than basic ones, because experiment shows, and field observation indicates, that abundant absorbed vapors accompany and facilitate the fusion of the rocks high in silica, whereas basic rocks are much more largely the results of dry fusion. Granites, for instance, are the commonest and most effective agents of contact metamorphism.

3. As regards the walls, sedimentary rocks possess varying susceptibilities. Highly siliceous sandstones and conglomerates, for example, are stubborn subjects, and manifest but slight alteration; but highly aluminous or calcareous beds are favorable to recrystallization, because they contain the alumina, iron, lime, magnesia and the alkalies which will combine with silica, under metamorphosing influences, to yield copious contact minerals. Of all rocks, impure limestones yield the most varied and interesting results.

4. With a favorable intrusion, the apparent distance to which the metamorphosing influence penetrates, depends on the angle of emergence of the intrusion. If it comes up at a low angle it may lie but a short distance below the surface for a considerable stretch on one side of the outcrop, so that the metamorphosed area may apparently extend to a great distance, although at no point far from the source of heat. Around a vertical dike the distance would naturally be less. Again, the alterations progress much less readily across the bedding of stratified rocks than along it. Hence, an intrusion that cuts across the bedding produces more widespread effects than does one parallel with it.

5. It is believed by many, especially among English and German observers, that there is very slight migration of material during metamorphism, and therefore that the contact minerals have resulted from the silica and the bases which were practically in the same places before the intrusion as after it. It follows that there has been no chemical introduction or substitution, but only rearrangement of molecules during the process. An analysis, therefore, of a reasonably large-sized sample would indicate the composition of the original rock, except so far as water, carbonic acid and other volatile ingredients have been driven off. From observations upon an intrusion of granite in Westmoreland, England,

which cuts a decomposed, basic, amygdaloidal lava, Alfred Harker concluded that the migration had not exceeded one twentieth of an inch. But among the French much greater power of chemically affecting the walls is attributed to intrusions, and in instances it certainly seems as if, in addition to the fluorine and boron which we all know penetrate into wall rocks during the escape of mineralizers, hydro-fluosilicic acid might impart silica and that some of the bases, and especially the alkalies, might migrate in heated solutions, to a moderate distance.

The soundness of the belief in the migration of material from the intrusive mass has been demonstrated beyond question in later years by the study of the garnet zones produced from limestones by moderately or decidedly acidic igneous rocks. The occasional appearance of copper ores in the zones has given the problem technical as well as purely scientific importance. There are two points of especial significance which have been developed. For years it was assumed that the variety of garnet present was grossularite, $3CaO,Al_2O_3,3SiO_2$. Since alumina in the form of kaolinite, and silica, as comminuted quartz, chalcedony, chert, etc., are common and widespread ingredients in limestone, the conclusion was reached that under the influence of heat from the intrusive mass, the kaolinite and quartz or other forms of silica, had combined with the calcite, driving off the carbon dioxide and producing grossularite as the result. Chemical analyses, which are now available from many localities, have shown however that the garnet is grossularite only in small part, but that it is usually or predominantly andradite, $3CaO,Fe_2O_3,3SiO_2$, a variety which cannot be distinguished from grossularite with the eye. Ferric oxide is not found in the limestones in anything like the amount called for and it has therefore been necessary to derive it from the igneous rock. This first point is corroborated by a second as follows. The contact zones from limestones are often provided with great bodies of magnetite or specular hematite, which observers have been unable to explain satisfactorily in any other way than by emissions from the igneous mass in its cooling stages. The Iron Springs district, Utah, furnishes a good illustration, but there are many more in the southwestern United States and in Mexico. Many geologists have thus come to believe that an intrusive mass

in its cooling stages emits water, gas, and probably other vapors, and with them silica, iron, often copper and very likely alumina. While garnet (andradite) is commonest, diopside, vesuvianite, epidote, wollastonite and some rarer minerals are frequent associates. Copper ores with small gold values are more frequently associated than other ores, save those of iron.

The ore-bodies are of irregular shape and distribution. The garnet and related lime-silicates were the first minerals to form and were followed by the magnetite, pyrite and chalcopyrite.

6. Notwithstanding the truth of the foregoing generalities, it is a curious fact that contact effects are sometimes strangely lacking where we would naturally expect them, and they are often of varying intensity and irregular distribution, where they do occur. These anomalies can in part be explained by the general principles already cited, of which no doubt the presence or absence of mineralizers, the superheated or relatively cold condition of the intrusion are chief. But every observer of wide experience is sometimes much puzzled by what he meets in Nature.

I. The Rocks Produced by Contact Metamorphism.

Although the principal results of contact metamorphism are manifested in the walls of the intrusion, the igneous rock is itself influenced. It is therefore necessary to note both the *internal* and the *external* effects, or those upon the intrusion and those upon the walls. The area over which the latter are manifested is often called the aureole, and the concentric rings of decreasing alteration as one passes outward from the intrusion are called zones.

Internal Effects. — The igneous rock suffers a relatively rapid loss of heat in its marginal portions as compared with its interior, and as a result it very commonly assumes a porphyritic, felsitic or even, just as the contact, a glassy texture, although it may be granitoid within. Where these textures are well developed the passage from one to the other is extremely gradual, and if the wall rock has been originally a shale or a clay that has been baked to a dense mass, one may need microscopic examination to determine where the intrusion ends and the wall rock begins. The changes in texture in the intrusion are accompanied more or less by changes in chemical composition and in not a few cases progres-

sive analyses have shown the margins to be much more basic than the interior of the intrusion. The chilling of the former has thus produced chemical rearrangements in the magma previous to consolidation.

External Effects. — Recalling the statement earlier made that within the limits already set forth the character of the intrusion is immaterial, the most convenient and intelligible method of treatment will be to briefly outline several typical cases wherein the commoner sedimentary rocks are known to have been affected, and then to refer to one or two instances wherein igneous or regionally metamorphic ones have suffered alteration. The same order will be preserved for the sediments as appears under Chapters VII. and VIII.

Breccias are too limited in distribution to be a serious factor. Conglomerates and sandstones so generally consist of silica, that they supply but little raw materials of a favorable kind. The small amounts of alumina present may combine with the silica to afford sillimanite (Al_2O_3 SiO_2) and stimulated circulations of hot water may cause added deposition of quartz around the grains so as to develop increased hardness.

With shales and clay rocks, even if in the form of slate (see later, p. 145), the effects are more pronounced; and around intrusions in them well-marked and well-identified zones have been described.

At the contact of the igneous rock with the sediment a breccia or "mixed zone" of intrusive and fragments of wall-rock is sometimes, although not always, met. More commonly the shales, slates, clay or their kindred rocks are baked and altered to a dense flinty product known as a hornfels or hornstone, which latter name in this sense is, however, not to be confused with its use for flints and cherts. It breaks in irregular, angular masses and has a very close resemblance to dense trap. Its mineralogy is, as a general thing, a subject for microscopic study, but it may be said that biotite in small scales is rather the most widespread mineral present, and that andalusite, garnet, cyanite, staurolite, tourmaline, ottrelite, rutile, hornblende, feldspars and other minerals more or less characteristic of such surroundings frequently appear. They may be of considerable size and the prisms of andalusite of the variety chiastolite, with the light and dark maltese crosses showing in their

cross-sections, are especially frequent. As the contact is left the hornfels often passes into mica schist. Farther out the mineralogical changes become less marked; the andalusite and other crystals are less and less well developed and finally shade into mere dark spots or aggregates of biotite, magnetite and bituminous matter. When even these fade out the unchanged sediment is met. In some localities it has therefore been possible to establish three zones, which are, in the reverse order of the above succession, the knotty or spotted slates, the knotty mica schists, and the hornfels, usually with andalusite. By knotty is meant the aspect given by the larger contact minerals in the midst of finer aggregates. These are the names adopted for a well-known contact studied by the eminent German petrographer, Rosenbusch, in the Vosges Mountains.

At a famous American locality in the Crawford Notch of the White Mountains, on the slopes of Mt. Willard and not far from the Crawford House, the granite has penetrated an argillitic mica schist or micaceous slate, and the zones are somewhat different. G. W. Hawes in 1881 established the following seven: 1. The argillitic mica schist (chloritic); 2. Mica schist (biotitic); 3. Tourmaline hornstone; 4. Tourmaline veinstone (a small contact band, rich in tourmaline); 5. Mixed schists and granite; 6. Granite porphyry (biotitic); 7. Granite (hornblendic). This is one of the most complete and best-exposed contacts known, and illustrates both external and internal effects.* The succession illustrates the alteration of chlorite to biotite by the granite, and then near the contact the development of tourmaline from the boracic and fluoric emanations which were afforded by it. On the southeast corner of Conanicut Island, in Narragansett Bay, granite has penetrated Carboniferous shales, as described by L. V. Pirsson,† and has baked them to compact hornfels near the contact. Spotted slates are likewise met resembling those described above. Immediately beneath the diabase of the Palisade ridge at Hoboken, N. J., the Triassic shales are baked to a compact hornfels with abundant tourmalines and near Beemerville, N. J.,‡

* Hawes' paper is in the *American Journal of Science*, January, 1881, p. 21.

† L. V. Pirsson, On the Geology and Petrography of Conanicut Island, R. I. *American Journal of Science*, Nov., 1893, p. 363.

‡ J. F. Kemp, *Trans. New York Acad. Sci.*, XI., p. 60.

a great dike of nepheline-syenite has come up through Ordovician shales and has altered them in places to remarkably dense, black hornfels. Near Crugers, on the Hudson River, mica-diorites have penetrated mica schists and have developed in them a considerable number of characteristic, contact minerals, but the changes in the schists are not specially apparent to the eye.* As western and other eastern areas are further studied, no doubt additional cases will be fully described. Many are known and await careful field work.

The contact effects on limestones furnish extremely interesting phenomena, involving a series of minerals somewhat different from those just described. Pure limestones often recrystallize into marbles; but where the contact minerals contain greatly increased percentages of silica and iron oxides, the introduction of these substances from the intrusive mass is proven. The limestones then become thickly charged with biotite, garnet, vesuvianite, scapolite, pyroxenes and amphiboles, tourmaline, spinel, and not a few more. Garnet and vesuvianite are especially characteristic. Good contacts have been met at several American localities. Near St. John, N. B., † granite has penetrated Laurentian limestone and has developed a garnet zone, with more or less pyroxene. Diorites cutting or including limestone in the Cortlandt series ‡ have caused the formation of pyroxene, scapolite, hornblende and other minerals.

In the valley extending from Warwick, N. Y., southwest to Sparta, N. J., are most instructive exhibitions, and rich mineral localities are based on them. Granite is the principal intrusive. § The western Adirondack region of New York contains many more where intrusives and limestone come together. The southwest and Mexico are prolific in garnet zones, which at times contain copper mines. They have thrown much light on ore-deposition. Abroad, the region about Christiania in Norway has proved to be classic ground for these phenomena, and a great contact of diorite on Triassic limestone at Predazzo in the Tyrolese Alps has produced the characteristic zones on a grand scale.

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* G. H. Williams, *Amer. Jour. Sci.*, Oct., 1888, 265.

† W. D. Matthew, *Trans. N. Y. Acad. Sci.*, XIII., 194.

‡ G. H. Williams, *Amer. Jour. Sci.*, Oct., 1888, 267.

§ J. F. Kemp and Arthur Hollick, *Annals N. Y. Acad. Sci.*, VII., 644.

Increasing experience, in the West and in Mexico, has shown that copper ores are often deposited along the contacts of eruptives and limestone. Thus in the Seven Devils district, in western Idaho, bornite occurs between diorite and white marble, and is mixed with epidote and garnet as a gangue, both being minerals characteristically developed in these surroundings.

The inclusions of wall rock caught up by an advancing intrusion on its way to the surface are instructive examples, and often are afterwards found entombed in the igneous rock and more or less altered. The lava flows of Vesuvius and the ejected bombs have been of extraordinary interest in this respect. Limestones are frequent among them and they exhibit the same zones as the larger occurrences. Vesuvianite, in fact, received its name from this association.

Of the remaining members of the grand division of the Aqueous rocks, the Carbonaceous are the principal ones deserving mention. Coal seams of the normal bituminous variety have been cut in not a few places by igneous dikes, and display in a marked degree the metamorphosing effect. The volatile hydrocarbons have been driven off and the coal has become an impure coke. The Triassic coal basins of Virginia and North Carolina exhibit many instances where diabase dikes have wrought the change, and in the region of Puget Sound basalt intrusions have effected similar results. In Colorado and New Mexico, the near approach of an igneous sheet has brought about the formation of anthracite, and in fact all grades of coal can be detected from rich bituminous to hard anthracite, according to the nearness of the dike or laccolite.

Reference may also be made to the hills of soft magnetite, near Cornwall, Pa., where a great dike of diabase has apparently caused the replacement of calcareous shales with pyritous magnetite.

Where intrusions cut other igneous or metamorphic rocks the effects are much less apparent, because the walls are resistant to change, being themselves already crystalline. Around granites, however, even in these conditions, great pegmatite dikes and veins are copiously produced, which seems to be in large part brought about by escaping heated vapors and solutions.

Remarkable cases of contact metamorphism are, however, certainly caused by these last named agents. As rocks they are not

specially abundant, although of great scientific interest. Some intrusions have emitted copious emanations of hydrofluoric and boracic acid in conjunction with superheated steam. These vigorous reagents have attacked the wall rocks, when originally formed of crystalline silicates, making them porous and cellular from the destruction of feldspars, and have often caused the crystallization of quartz, tourmaline, topaz, fluoric micas, fluorite, apatite and other characteristic minerals of which cassiterite is of much economic importance. Such metamorphic products when essentially consisting of quartz and mica are called greisen. Tourmaline granites likewise result. It is not to be overlooked, however, that mineralizers have also played a large part in the cases earlier cited, nor should the remark be omitted in conclusion that they and similar agents have been of very great importance in the formation of ores.

CHAPTER X.

The Metamorphic Rocks, Continued. The Rocks Produced by Regional Metamorphism. Introduction. The Gneisses and Crystalline Schists.

Introduction.

This subdivision embraces rocks which differ widely among themselves, but which have nevertheless important features in common. The following generalities are applicable in a large way and will serve to emphasize some of the most important points.

1. Regionally metamorphosed rocks are all more or less perfectly crystalline. This is least developed in the slates.

2. They are all more or less decidedly laminated or foliated, although some amphibolites, marbles and serpentines are quite massive. The laminations are due to the arrangement of the constituent minerals, and especially the dark-colored ones, in parallel alignment, so that light and dark layers stand out conspicuously. The terms bedded and stratified should never be applied to them because the banding is largely due to dynamical processes, and has no necessary connection with original sedimentation.

3. They are of ancient geological age or else are in greatly disturbed districts.

It is important in connection with these rocks to distinguish between the effects produced by heat or thermal metamorphism and the effects produced by mechanical forces or dynamic metamorphism. By thermal metamorphism we understand the alterations caused by heat not necessarily accompanied by the mechanical effects such as shearing, crushing and the like, that are comprehended under dynamic metamorphism. Contact metamorphism is of course a variety of the former which, however, is also brought into play alike when rocks are so deeply buried that they come within the sphere of influence of the earth's interior heat, and when from dynamic stresses, they are crushed so that their particles move or slide under great pressure on one another and develop heat by friction. If we imagine for a moment great bodies of

rocks which have definite crushing resistances, buried under a load of overlying strata, so deep within the earth that their limits of resistance are exceeded, yet so confined that they cannot fly apart, we perceive that they must yield by internal crushing, and if the upheaval of a mountain range eases the strain, that they must flow as a mass. It is to this flow, accompanied by shearing, that the lamination of metamorphic rocks is largely due. Prominent or conspicuous minerals are strung out in parallel lines, oftentimes with wavy folds and curves, and in the end a foliated or laminated structure is superinduced that suggested the bedding of sediments to the early geologists. It is not to be denied, however, that the laminations do at times correspond to original bedding, because where the contrasts in chemical and mineralogical composition among the layers are pronounced, they doubtless mark such correspondence, but cases are well known of old conglomerate beds passing directly across the prevailing schistosity of a gneissic district.

During these shearing and flow movements large crystals, such as the feldspars of porphyries, and the larger uncrushed nuclei of minerals in a general pulp are squeezed and stretched into lenses, and remain like eyes between eyebrows, so that they are called "Augen" from the German word for eyes. Swirling curves and eddies in the laminations are also familiar phenomena and cannot be explained in any other way.

These changes may take place without mineralogical alteration, as when granitoid rocks pass into gneisses which contain simply the crushed fragments of the originals, but as a general thing new combinations are formed in the metamorphosed rock. Pyroxene passes into hornblende; soda-lime feldspars become scapolite or saussurite, and other changes ensue which are best detected with the microscope. Sedimentary rocks suffer entire recrystallization, and sometimes so thoroughly lose their original characters that no clue is afforded as to their history. In regional metamorphism precisely as in the case of the contact metamorphic rocks, it is generally believed that there is no change in composition, except perhaps by the loss of volatilizable ingredients, but only rearrangement of elements. A gross analysis of a reasonably large sample will therefore give a clue to the composition of the original. Heated waters, generally

charged with mineral matter and steam, have no doubt contributed largely in bringing about the final results.

The Regionally Metamorphosed rocks will be described under the following heads:

1. The Gneisses and Crystalline Schists.
2. The Quartzites and Slates.
3. The Crystalline Limestones and Dolomites: The Ophicalcites, Serpentines and Soapstones.

The Gneisses.

Introductory.—Gneiss is an old word which originated among the early German miners in the Saxon districts. It was especially applied by them to laminated rocks of the mineralogical composition of granite, and in this sense it is quite widely employed to-day. But there are many important gneisses which correspond in mineralogy to the other plutonic rocks, and which are quite as properly designated by this name, so that gneiss has come to be a term that is of loose geological significance very much as is trap, but that is none the less useful for this reason. We may therefore define gneiss as a laminated, metamorphic rock which usually corresponds in mineralogy to some one of the plutonic types. Gneisses differ from schists in the coarseness of the laminations, but as these become finer they pass into schists by insensible gradations. Varieties are sometimes indicated by prefixing the name of the most prominent silicate, usually one of the ferro-magnesian group, thus hornblende-gneiss, biotite-gneiss, pyroxene-gneiss, but we also often speak of quartz-gneiss, orthoclase-gneiss, plagioclase-gneiss, garnet-gneiss and the like.

It is evident at once that the above names are incomplete. Hornblende-gneiss, for instance, does not indicate whether the rock contains orthoclase or plagioclase, quartz or no quartz, and the other ones cited are open to the same or similar objections, and if in the endeavor to embody fuller descriptions we string together the names of all the minerals in the rock, we employ an objectionable and awkward method of coining words. A system has, however, been suggested by C. H. Gordon,* in a recent paper that obviates many of these objections and that is adopted below with

* *Bulletin of the Geological Society of America*, VII., 122.

some abbreviation to make it suitable for an elementary book. It is based on the parallelism which exists between the mineralogy of gneisses and that of the massive plutonic rocks, and it avails itself of the short names of the latter, which indicate in each case, a definite combination of minerals, to describe the aggregates present in the former. Two sedimentary terms are also added.

Massive Type.	Gneiss of Corresponding Mineralogy.	Sedimentary Type.	Derived Gneiss.
Granite	Granitic Gneiss	Conglomerate	Conglomerate Gneiss
Syenite	Syenitic Gneiss	Sandstone	Quartzite Gneiss
Diorite	Dioritic Gneiss		
Gabbro	Gabbroic Gneiss		
Pyroxenite	Pyroxenitic Gneiss		
Peridotite	Peridotitic Gneiss		

Dr. Gordon also suggests that, when gneisses are evidently dynamic derivatives from a massive rock, this relationship be indicated by using the terms granite-gneiss, syenite-gneiss and so on. If, however, differentiations in the magma before crystallizing have given rise to laminations, he advocates that such be distinguished by the adjective gneissoid, as gneissoid gabbros.

Gneisses are occasionally met which do not exactly correspond to any of the above names. Chlorite, for example, is a not uncommon mineral, and while it is evidently an alteration product from pyroxene, hornblende or biotite, the original mineral is not at once apparent, and some such name as chlorite-gneiss must be used. In the same way cordierite-gneiss describes those rare varieties containing cordierite (iolite and dichroite are synonyms of cordierite); sillimanite-gneiss, garnet-gneiss, epidote-gneiss and others convey in their names their characteristic features.

Analyses of Gneisses.

Chemical analyses often enable us to trace back gneisses to their original rocks, whether igneous or sedimentary, but it requires careful study of correct type analyses and some familiarity with their ranges in composition to do it. So far as their number admits the analyses quoted on earlier pages will be found suggestive:

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	Loss or H_2O
1.	76.61	12.45	...	1.33	0.84	...	5.42	3.12	0.53
2.	74.95	9.42	7.47	...	1.65	0.13	2.02	4.05	1.02
3.	73.47	15.07	1.15		4.48	0.12	0.38	5.59	...
4.	71.46	15.06	...	2.43	1.40	0.42	5.17	3.23	0.83
5.	69.35	18.83	2.00		5.94	...	3.78		...
6.	69.94	14.85	7.62	...	2.10	0.97	4.33	4.30	0.70
7.	61.96	19.73	...	4.60	0.35	1.81	2.50	0.79	1.82
8.	57.66	22.83		7.74	1.16	3.56	5.72	0.60	1.50
9.	57.20	19.57	9.52	0.59	5.73	4.40	0.28	2.13	0.88
10.	54.89	13.67	1.35		5.63	4.70	8.34	1.95	2.76

1. Granite gneiss, west side of Black Hills, 40th Par. Survey, I., p. 110. R. W. Woodward, Anal. 2. Called a dioritic gneiss in reference, contains hornblende, quartz, plagioclase, orthoclase. *Idem*, R. W. Bunsen, Anal. 3. Conglomerate gneiss, so-called granite; Munson, Mass. Quoted by G. P. Merrill, Stones for Building and Decoration, p. 418. 4. Granite gneiss, Iron Mountain, Wyo., R. W. Woodward, Anal. See under No. 1. 5. Dark variety of No. 3. 6. Granite gneiss, derived from a hornblende granite, Trembling Mountain, Quebec, Fundamental Laurentian of Logan. F. D. Adams, Amer. Jour. Sci., July, 1895, p. 67. W. C. Adams, Anal. 7. Quartzitic gneiss, with garnet, sillimanite, graphite and pyrite; St. Jean de Matha, Quebec, *Idem*, N. N. Evans, Anal. 8. Granite gneiss, probably a metamorphosed clay or slate. Trembling Lake, Quebec. Contains garnets and sillimanite, F. D. Adams, Amer. Jour. Sci., July, 1895, p. 67, W. C. Adams, Anal. 9. Dioritic gneiss, New York City, P. Schweitzer, Amer. Chemist, VI., 457, 1876. 10. Gneiss containing malacolite, scapolite, orthoclase, graphite, pyrite. Rawdon, Quebec. See under No. 8.

Comments on the Analyses. — Nos. 1, 4 and 6 are clearly derived from granites, presumably by dynamic metamorphism. The analyses correspond closely in their general features with those given on p. 33 except that the Al_2O_3 of No. 1 is a trifle low, and the Fe_2O_3 of No. 6 a trifle high. Nos. 3 and 5 are now known to be metamorphosed Cambrian conglomerate, although so thoroughly recrystallized as to be a well-known, commercial granite. The conglomerate must have come from granitic or dioritic original rocks. Nos. 7 and 8 correspond to the analyses of slates as noted by F. D. Adams in the original reference (see also under slates, p. 145). No. 10 as noted by Adams is of doubtful interpretation. The high alkalies, lime, magnesia and the moderate silica suggest a basic syenite or trachyte, but the alumina is exceptionally low for these. It may be a tuff or a slightly altered sediment from these originals. No. 2 is a very anomalous rock, and it is difficult to refer it to an original diorite, it is so high in silica and so low in alumina. The iron is very large for so acidic a rock.

No. 9 is undoubtedly an altered sediment as indicated by the local geology. Nothwithstanding the anomalies of composition, chemical analyses supply one of the surest clues to the geological history of gneisses and it is to be hoped that they will be multiplied in America. At present but few are available, far fewer than of igneous rocks.

Alteration.—The alteration of gneisses is similar in all respects to that of their corresponding massive types. The feldspars alter to kaolin, the micas and hornblende to chlorite and the rock softens down to loose aggregates that contribute heavily to the sedimentary rocks.

Distribution.—Gneisses are abundant in ancient, geological formations. The early Archean is their especial home, and they form the largest part of its vast areas in Canada, around the Great Lakes, along the Appalachians and in the Cordilleran region. But no single division of geological time monopolizes them any more than such an one does plutonic rocks. There are Cambrian and even Carboniferous gneisses in New England, and dynamic metamorphism may produce them from massive rocks of almost any age. The later geological formations are, however, seldom buried sufficiently deep to be in favorable situations. Much the same holds true of Europe and the rest of the world. The gray and red gneisses of the mining districts about Freiberg, in Saxony, those of the Highlands of Scotland, those in Scandinavia, and the wonderful exhibitions of dynamic metamorphism in the Alps are to be cited as of unusual historic and scientific interest.

Granulite.—Granulite is a word that has possessed somewhat contrasted meanings according as it has been used in Germany, France or England. In Germany as first employed it was applied to a finely gneissoid rock that consists chiefly of feldspar, quartz and garnets. These original granulites have other minerals more or less prominently developed, of which cyanite, augite, biotite and hornblende are chief. The texture of the rock is extremely dense, and except for the garnets, cyanite or augite, the individual minerals are hardly discernible. Among French and English speaking peoples the name granulite has been applied to granitic rocks that appear to the eye to be chiefly quartz and feldspar, although the microscope may show muscovite. They are practically binary granites, or

rich quartz and feldspar gneisses. The name has also been used for coarse plutonic rocks that have been crushed down by dynamic metamorphism into a finely granular and homogeneous aggregate. But so far as metamorphic rocks have been met in America, cases are very rare which cannot be satisfactorily described without the use of this word, which has been so perverted from its original application as to be practically valueless without an accompanying explanation.

The Crystalline Schists.

The crystalline schists have finer laminations than the gneisses, but in other respects the mineralogy is often much the same, and as already stated no very sharp line can be drawn between them. It is important to note that the words "schiste" of the French and "Schiefer" of the Germans are applied to shales, slates and metamorphic schists indiscriminately, but in English schist is only used for metamorphic rocks. The more important schists are broadly classified, according to the principal ferro-magnesian silicate that is present, into the following three groups under which they will be taken up.

(*a*) Mica-schists.
(*b*) Hornblende-schists or Amphibolites.
(*c*) Various Minor Schists.

The Mica-Schists.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	H_2O
1.	82.38	11.84	...	2.28	...	1.00	0.83	0.38	0.77
2.	79.50	13.36	2.87	...	0.71	0.95	4.69	0.36	0.78
3.	69.45	14.24	...	6.54	2.66	1.35	2.52	4.02	0.52
4.	66.21	18.60	...	5.34	0.44	1.24	3.80	2.16	2.04
5.	62.98	16.88	2.48	5.00	tr.	1.58	7.45	3.02	...
6.	61.57	19.53	5.44	2.61	tr.	1.90	2.14	3.48	...
7.	60.49	19.35	0.48	5.98	1.08	2.89	3.44	2.55	3.66
8.	57.67	17.92	...	9.00	3.19	3.29	3.86	1.09	3.19
9.	55.12	24.32	6.13	4.99	tr.	tr.	2.83	2.71	...
10.	49.00	23.65	8.07	...	0.63	0.94	9.11	1.75	3.41

1. Mica-schist, rich in quartz, Monte Rosa, Switzerland, Zulkowsky, Sitz. Wiener Akad., XXXIV., 41, 1895. 2. Mica-schist, with quartz and green mica, Zermatt, Switzerland. Bunsen in Roth's Tabellen, 1862. 3. Garnetiferous mica-schist with feldspar, Brixen. Tyrol. Schönfeld and Roscoe, Ann. der. Chem. u. Phar., XCI., 1854, 305. 4. Mica-schist, near Meissen, Saxony, Hilger quoted in Roth's Tabellen, 1879. 5. Mica-schist, Crugers, N. Y., contains quartz, orthoclase, biotite, muscovite, a little oligoclase, etc. F. L. Nason for G. H. Williams, Amer. Jour. Sci., Oct., 1888.

259. 6. Crumpled garnetiferous mica-schists, *Idem*. 7. Argillitic mica-schist, G. W. Hawes, Geology of New Hampshire, Part III., 219. 8. Mica-schist near Messina, Sicily, Ricciardi, quoted in Roth's Tabellen, 1884, p. ix. 9. Staurolite mica-schist, with biotite, muscovite, quartz, sillimanite, garnet. See under No. 6. 10. Sericite schist, Wisconsin, Wis. Geol. Surv., I., 304.

Comments on the Analyses. — Like the majority of gneisses the mica-schists are more or less closely parallel with the granites in chemical composition because the constituent minerals are so largely the same in both. But where they have been formed from metamorphosed sediments such as shales, clays, and the like, the alkalies are often lower than in the case of siliceous igneous rocks, and, what is still more characteristic of sediments as contrasted with highly siliceous igneous rocks, the magnesia is in excess of the lime. A comparison of the above analyses with those of the rhyolites, trachytes, granites and syenites earlier given will forcibly bring this out. The local geology as well as the analyses, indicate that there is little doubt that Nos. 5, 6, 7 and 9 are altered sediments, and the presumption is strong that almost all the others are also.

Mineralogical Composition, Varieties.—The most prominent and abundant minerals in the mica-schists are quartz, muscovite and biotite. While they are more or less interleaved together, yet close examination of the coarser varieties shows that they are in layers irregularly parallel and to a large extent distinct. The minerals are in all degrees of relative abundance, quartz sometimes largely predominating and marking a passage to the quartzites, while again the micas may be in great excess. Both muscovite and biotite are met, the former being, perhaps, rather the more abundant. With these chief minerals are almost always associated very considerable amounts of feldspar, both orthoclase and plagioclase, and variable proportions of garnet, staurolite, cyanite, sillimanite, tourmaline, apatite, pyrite and magnetite.

The garnet and staurolite may exhibit surprisingly well developed crystals and illustrate the extraordinary power of certain compounds to crystallize under circumstances apparently ill-adapted to their perfect development.

Mica-schists embrace a series from rather coarsely crystalline varieties to others that are excessively fine-grained and that are near relatives of the slates. The minerals of the latter may be of

microscopic dimensions, and only the aggregate of shining scales reveals them as mica. Such aggregates, of a silvery white color but of composition essentially the same as normal muscovite, are called sericite, and the corresponding schists, sericite-schists. A soda-mica (muscovite and its relatives are potash micas) is called paragonite. Hydromica is a name applied many years ago by Dana to sericite, paragonite, and perhaps others resembling them, so that for these finely micaceous schists, especially in our eastern states, hydromica schist is a field name that has been largely used in practice and in geological reports. These fine-grained mica-schists that approximate slates are also made a special group by many, under the name phyllite, a very useful term and one to be strongly commended. Mica-schists are also met that are high in lime and that mark transitions to the crystalline limestones. The abundance of calcite or dolomite betrays them, and to such the names calcareous schist or calc-schist are applied.

Mica-schists result from the thorough metamorphism or recrystallization of sandstones, shales and clays, and also from the crushing and excessive shearing of igneous rocks, granitoid and porphyritic alike. A possible origin from ancient volcanic tuffs is always to be considered in the study of a district, but the questions of origin are obscure and are subjects for thorough chemical and microscopical investigation.

Alteration. — The mica-schists are rather resistant to alteration and often appear on mountain tops. When alteration does prevail, they soften to masses of quartz sand, chlorite scales and kaolin.

Distribution. — The mica-schists form the country rock over vast areas in New England and to the south along the eastern Appalachians. Although long regarded as of uncertain or obscure geological relations they are now recognized as being in large part at least metamorphosed Cambrian and Ordovician shales or related sediments. Around Lake Superior and in the regionally metamorphosed areas of the West they are not lacking.

The Hornblende Schists or Amphibolites.

Introductory. — Under dynamic metamorphism the basic igneous rocks whose chief bisilicate is pyroxene, pass very readily into hornblendic rocks, with a greater or less development of schistosity.

On account of the prevailing parallel arrangement of the prismatic crystals of hornblende, schistosity is seldom entirely lacking, but where less distinct the name amphibolite has proved to be a useful alternative, and indeed is of wide general application. Sedimentary rocks are also known in rarer instances to yield similar results.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	H_2O
1.	52.39	16.13	1.64	1.44	8.76	4.70	1.42	2.59	0.17
2.	50.44	8.18	1.06	6.28	11.55	17.63	0.50	2.98	0.98
3.	49.19	18.71	5.03	4.04	5.92	7.98	0.77	1.44	5.05
4.	46.31	11.14		21.69	9.68	tr.		6.91	4.44
5.	44.49	16.37	5.07	5.50	7.94	7.50	0.56	2.59	4.99

1. Hornblende-schist, Grand Rapids, Wis., Geology of Wis., IV., 629. Also, Fe in pyrite, 0.34 ; S, 0.39 ; P_2O_5, 0.28 ; Ca in apatite 0.815. 2. Pseudo-diorite of Becker, Knoxville, Calif., Monograph XIII., U. S. Geol. Surv., 101, W. H. Melville, Anal. Also, MnO 0.213, Cr_2O_3 0.480. 3. Hornblende-schist derived from gabbro, Lower Quinnesec Basin, Wis. R. B. Riggs for G. H. Williams, Bull. 62, U. S. Geol. Surv., p. 89. Also, CO_2 1.82. 4. Hornblende-schist near Cleveland Mine, Mich., Foster and Whitney, Rept. on the Iron Lands of Lake Superior, p. 92. 5. Hornblende-schist, Lower Quinnesec Falls, Wis., R. B. Riggs for G. H. Williams, Bull. 62, U. S. Geol. Surv., p. 91. Also CO_2 5.38.

Comments on the Analyses. — The analyses indicate basic rocks, of decidedly variable composition. Nos. 3 and 5 are certainly sheared igneous rocks. No. 2 is regarded by Becker as a metamorphosed sediment. It is quite different from the others in its low alumina, and its great excess of magnesia over lime. No. 1 appears to be an altered igneous rock and No. 4 is probably the same. Aside from exhibiting the composition of these rocks, the analyses are interesting when compared with those of the basic diorites (p. 64) and the gabbros and pyroxenites (pp. 78, 81).

Mineralogical Composition, Varieties. — The most abundant mineral in these rocks is naturally hornblende. With it are associated oftentimes biotite, augite, plagioclase, garnet, magnetite, pyrite and pyrrhotite ; but quartz, except as forming veinlets, is not often met nor is it to be expected in such basic rocks. The commonest variety of hornblende is black to the eye, but is green in thin section. It forms prismatic crystals from moderately coarse to microscopically fine. The prisms are interlaced so as to make a very tough aggregate and one that breaks with difficulty under the hammer. Light green actinolite may also form schists. Black scales of biotite appear interlaminated with the hornblende. The augite is not

readily distinguished from the hornblende with the eye alone. It is in large degree the remnants of original pyroxenes that have partially passed into hornblende during the metamorphic process. The plagioclase also represents to a great extent the feldspar that was in the original gabbro or other igneous rock from which the amphibolite has been derived. The plagioclase is often replaced by secondary products, such as epidote, calcite, scapolite and others, which together make up the aggregate formerly called saussurite, and regarded as an individual mineral. The minor accessories, magnetite, pyrite, pyrrhotite and garnet deserve no special mention. Except magnetite, which never fails, they are of more or less irregular occurrence.

Alteration.—The hornblende passes readily into chlorite and softens to a scaly mass with the separation of much limonite that yields a characteristic, rusty outcrop. If any pyrite or pyrrhotite is present it greatly expedites the alteration by its contribution of sulphuric acid. The feldspars yield calcite and kaolin and the whole mass becomes a rusty clay or soil.

Occurrence.— The hornblende-schists constitute individual belts in schistose regions in the midst of other metamorphic rocks and also great areas by themselves. Dikes and sheets of diabase and plutonic masses of gabbro in districts that have been subjected to violent dynamic upheavals readily pass into them. The same areas in the Eastern States that were cited under gabbro contain them, and they are minor members in the schistose districts of New England. Around Lake Superior they form a most important part of the geology of the iron ore regions, and in the Black Hills, the Rocky Mountains and the ranges of California they are often met.

Various Minor Schists.

Under this collective term are assembled a series of minor rocks, no one of which compares in importance with the schists already mentioned, but all of which may be met as subordinate members of metamorphic districts. There are also others in considerable variety which are esteemed too unimportant for an elementary book.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	H_2O
Chlorite schist.									
1.	49.18	15.09	12.90		10.59	5.22	1.51	3.64	1.87
2.	47.10	2.14	44.33		0.36	0.13			5.19

Talc schist.	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	H_2O
3.	58.66	9.26	4.42		0.94	22.78			4.09
4.	50.81	4.53	3.52	4.26		31.55			4.42
Epidote schist.									
5.	41.28	18.48	9.44	8.20	7.04	7.48	2.21	3.52	2.74
Eclogite.									
6.	48.89	14.46	2.00	7.15	13.76	12.21	0.17	1.75	0.40
Glaucophane schist.									
7.	47.84	16.88	4.99	5.56	11.15	7.89	0.46	3.20	1.98

1. Chlorite schist, Klippe, Sweden, Cronqvist for Törnebohn. Quoted by Roth, Gesteinsanalysen, 1884, p. viii. 2. Chlorite schist, Foster Mine, Mich., C. F. Chandler, Geol. of Mich., I., 91. 3. Talc schist, Fahlun, Sweden, Uhde quoted by Roth, Gesteinsanalysen, 1861, 56. 4. Talc schist, Gastein, Austria, R. Richter. *Idem.* 5. Epidote schist from diabase, South Mountain, Pa., C. H. Henderson, Trans. Amer. Inst. Min. Eng., XII., 82. 6. Eclogite, Altenburg, Austria, Schuster, Tscher. Mitt., 1878, 368. 7. Glaucophane schist, Monte Diablo, Calif., W. H. Melville, Bull. Geol. Soc. Amer., II., 413.

Comments on the Analyses. — These analyses are too variable to admit of much in the way of comparative remarks, for the rocks are so totally unlike. No. 1 suggests an original diabase or some such rock. No. 2 is abnormally rich in iron, doubtless in large part from magnetite or hematite. The high magnesia in Nos. 3 and 4 is characteristic and indicates their close relations with serpentines. No. 5 is an altered diabase. No. 6 is of a rock variable in its mineralogy and obscure in its history. No. 7 is practically a hornblende-schist with glaucophane, an amphibole that is high in soda, instead of common hornblende.

Mineralogical Composition, Varieties. — The chlorite schists are marked by the presence of this green micaceous mineral in large amount. More or less quartz is also generally present, and not infrequently plagioclase, talc, epidote and magnetite. The schistose texture is pronounced. The chlorite-schists are manifestly alteration products from some rock, with abundant, anhydrous, iron-alumina silicates. Hornblende-schists, presumably from basic igneous rocks are the general source. Certain chlorite-schists are often called "green schists."

Talc-schists are characterized by sufficient talc to make this mineral prominent and in addition they have quartz as the next most abundant constituent. Feldspar may at times be noted, and some micaceous mineral is not rare. Care is necessary not to confuse fine scales of the last named with talc itself. Various accessory

minerals likewise occur, and the magnesian carbonates, dolomite and magnesite are often present. Obviously the talc-schists have resulted from the alteration of some rock with one or more anhydrous, magnesian silicates that lacked iron. Tremolite and enstatite are the most available, but the original sources of these are often obscure. Siliceous dolomites or intrusive pyroxenites at once suggest themselves, but the iron must of necessity have been low, so as not to yield serpentines.

Epidote-schists result when the ferro-magnesian silicates and the plagioclases are so favorably situated with reference to each other as to establish mutual reactions. They especially arise as phases in the metamorphism of pyroxenic or hornblendic rocks, such as diabase, hornblende-schists and the like. Eclogite is a rock scarcely known in America, having as yet only been noted in the Marquette District, Mich. (Geol. of Wis., III., 649) and in California. It is a well recognized variety, however, in Europe. It consists of bright green amphiboles and pyroxene, of garnet and of a variety of minor minerals. In ordinary determination it would not be distinguished from a garnetiferous, actinolite schist. Glaucophane is a blue soda amphibole that is rare in America, except in the Coast range of California, where it characterizes certain important schists. The rocks have a pronounced blue shade, and contain in addition quartz and feldspar. In California they certainly are altered shales. Graphite appears quite commonly as a characteristic mineral of certain schists, and may justify the use of the name graphite schist. More or less mica, and always quartz and feldspar are associated.

Distribution. — Chlorite-schist and talc-schist are not uncommon members of our larger metamorphic series, especially along the Appalachians in New England and around Lake Superior. Epidote-schist is less common in the same relations. The occurrence of eclogite and glaucophane-schist has already been cited. Graphite-schist is not infrequent in the metamorphosed Paleozoic strata of the East.

CHAPTER XI.

The Metamorphic Rocks, Continued. The Rocks Produced by Regional Metamorphism. The Quartzites and Slates. The Crystalline Limestones and Dolomites, Ophicalcites, Serpentines and Soapstones.

The Quartzites.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	H_2O	Sp. Gr.
1.	97.1	1.39	1.25		0.18	0.13				
2.	96.44	1.74		0.33	0.17	0.22	0.13	0.19	0.90	
3.	84.52	12.33		2.12	0.31	tr.	0.11	0.34	2.31	2.74

1. Quartzite, Chickies Station, Penn., Penn. Geol. Surv. Rep. M., p. 91. 2. Sandstone partly altered to Quartzite, Quarry Mtn., Ark., R. N. Brackett for L. S. Griswold, Geol. of Ark., 1890, III., 140, 161. 3. Quartzite, Pipestone, Minn., W. A. Noyes in Minn. Geol. Surv., I., 198.

Comments on the Analyses.—There is no essential difference in the analyses of quartzites and sandstones, as the few quoted above will show, but doubtless the resulting quartzite is somewhat richer in silica than the original sandstone. Comparatively few analyses of quartzites have been made in America.

Mineralogical Composition, Varieties.—The quartzites are metamorphosed sandstones, and differ from the latter principally in their greater hardness, and to a certain extent in their fairly pronounced crystalline character. These qualities are due to the presence of an abundant siliceous cement that is crystalline quartz, and that is often deposited around the grains of quartz of the original sandstone, so as to continue their physical and optical properties. The original grains have, therefore, had the power of controlling the orientation of the molecules of the new silica as it crystallized. When the original sandstone has been argillaceous the resulting quartzite contains mica and especially muscovite, and with increase of the mica, such quartzites pass through the intermediate varieties of quartz-schist into mica-schists. A very curious and more or less micaceous variety is the so-called flexible sandstone or itacolumite, whose grains have the power of slight movement on one another from their loosely interlocked arrangement, so that thin

slabs may be bent through a considerable arc. Quartzites also result from pebbly sandstones and conglomerates, and the pebbles of these latter are often flattened by the dynamic movements with which the metamorphism is at times associated. There is no sharp line of demarcation between quartzites and sandstones, and while the extremes of soft sandstones and hard quartzites are entirely different, the determination of intermediate varieties is more or less arbitrary.

Alteration. — Quartzites sometimes soften to sand on their outcrops, and in the process, almost the last vestiges of alumina or lime may be removed. In this way the sands in analysis No. 1, p. 97, were formed. In general, however, they are excessively resistant rocks, and tend to form prominent ledges.

Distribution. — Quartzites occur in almost all series of metamorphosed sediments, and as these are best developed in the later Archean (Huronian, Algonkian) strata, they especially characterize them. In the metamorphic belt in New England and along the Appalachians, they are frequent, as well as in the Huronian, around Lake Superior and Lake Huron and in the similar areas of the West.

THE SLATES.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	H_2O
1.	66.45	13.38	1.71	1.41	2.86	6.28	0.05	0.90	4.03
2.	66.00		24.60		tr.	tr.	3.67	2.22	3.00
3.	65.85	16.65	...	5.31	0.59	2.95	3.74	1.31	3.10
4.	64.57	17.30	7.46		1.16	2.60	1.99	...	4.62
5.	63.31	16.16	3.79		0.15	4.44	7.56	1.54	2.65
6.	60.50	19.70		7.83	1.12	2.20	3.18	2.20	3.30
7.	60.32	23.10	7.05		...	0.87	3.83	0.49	4.08
8.	57.00	20.10		10.98	1.23	3.39	1.73	1.30	4.40
9.	55.88	21.85		9.03	0.16	1.49	3.64	0.46	3.39
10.	54.80	23.15		9.58	1.06	2.16	3.37	2.22	3.90

1. Slate, Llanberis, Wales. Quoted by G. P. Merrill, Stones for Building and Decoration, p. 421, also MnO, 0.91, CO_2, 1.30. 2. Slate, Etchemin Riv., N. B., T. S. Hunt, Phil. Mag. (4), VII., 237, 1854. 3. Roofing slate, Westbury, Can., *Idem.* 4. Roofing slate, Lehesten, Germany. Frick, quoted by Roth, Gesteinsanalysen, 1861, p. 57. 5. Damourite slate, Hensingerville, Pa., Geol. of Penn., Rep. M., 91. 6. Roofing slate, Wales, T. S. Hunt as under No. 2. 7. Slate, Lancaster Co., Penn., also FeS_2, 0.09. See under No. 1. 8. Roofing slate, Angers, France, T. S. Hunt, as under No. 2. 9. Blue black carbonaceous slate, Peach Bottom slate, York Co., Penn., also MnO 0.586, CoO tr., C 1.974, FeS_2 0.51, SO_3 0.022. See under No. 1. 10. Roofing slate, Kingsey, Quebec, T. S. Hunt, as under No. 2.

Comments on the Analyses.—The analyses are especially significant when compared with those of the shales and clays, p. 100, and with those of the mica-schists, p. 137, with which latter they are closely parallel. Two features at once impress the observer, the excess of magnesia over lime, and the excess of potash over soda. The former stamps their origin as from sediments rather than from igneous rocks of these percentages in silica, because this relative excess of magnesia as noted under the mica-schists is rather characteristic of sediments.

Mineralogical Composition, Varieties.—As the sandstones during metamorphism pass into quartzites, so the shales and clays become slates, when not so thoroughly recrystallized as to yield mica-schists or phyllites. The more sandy shales afford varieties that break irregularly and that lack homogeneity, but tough and even slates result from homogeneous clays and are among the most remarkable of rocks. The distinctive feature of slates as against shales is the possession of a new cleavage that may lie at any angle with the original bedding of the rock, and that has no definite relation to it. The cleavage has been developed by dynamic strains that have, beyond question, involved a shearing stress and some differential movement among the layers, though it may have been microscopic. As a matter of observation the component grains of slates have become flattened and lie parallel with the new cleavage, and any mica flakes or hornblende needles that may be present lie along it.

Various explanations have been advanced for slaty cleavage, and its artificial production in different substances has occupied several investigators. Based principally upon experiments performed by Professor John Tyndall, over forty years ago, it has been usually referred to a compressive force at right angles to its plane. Tyndall subjected blocks of wax to pressure, using wet glass plates as his buttress of resistance. The blocks were of course greatly reduced in thickness and were forced to spread or bulge laterally. Shortly afterward H. C. Sorby, partly on the basis of the flattening of the component grains, and the alignment of mica scales, explained the cleavage as due to planes of weakness caused by this new arrangement. Recently, G. F. Becker of the U. S. Geological Survey has repeated the experiments of Tyndall with modifications. So long

as the resisting glass plates were wet with water the slaty cleavage was developed, but when they were smeared with a heavy lubricating oil, although there was lateral expansion during compression, no bulging took place and no cleavage was developed. Manifestly therefore the frictional drag of the plates enters into the problem, and although the resolution of the forces involved is somewhat complex, a shearing stress results that is a strong factor in producing the cleavage.* In the case of the large beds or strata which are metamorphosed into slate in Nature, the case is even less simple, and the contrasts in rigidity, between the beds that yield slates, and their enclosing strata, are less pronounced than in the experiment, but there is little doubt that the compression and slight lateral flow which occasion a flattening of the grains and an alignment of the scaly minerals across the direction of application of the force in this way produce the cleavage. All slates have cross-cleavages, or, it may be, joints, more or less well developed, and one of these may even be perfect enough in connection with the regular cleavage, to cause the slate to break into small prisms available for slate pencils, for which in earlier years they were employed. All slate quarries also show curly slates, where quartz-veins or sandy and harder streaks in the original sediment have caused imperfections in the cleavage. It has been noted that in some quarries the available plates appear to become thicker in depth, as if the surface weathering had been a factor in developing the cleavages. Though commonly drab to black, they may be red, green or purple.

Slates pass by all intermediate gradations into phyllites and mica-schists. The word slate is also loosely used for shales that have never had any secondary cleavage induced in them, and this is especially true of the black, bituminous shales that occur with coal seams, but in strict, geological use, the new cleavage and metamorphism should be essentials of a true slate.

Alteration. — Slates are exceedingly resistant as is shown by their use in thin slabs for roofs, and they often constitute prominent ledges or even peaks. They soften down to a clay in the last stages of alteration, but always on the outcrop are more tender than in

* G. F. Becker, Finite Homogeneous Strain, Flow and Rupture in Rocks, *Bull. Geol. Soc. Amer.*, IV., 82, 1893.

depth, so that much dead work is unavoidable in opening quarries.

Distribution. — Our most prominent slates are Cambrian or Ordovican in age. Along the Green Mountains and especially in northern Vermont they are strongly developed. Again in eastern Pennsylvania, in Virginia and in Georgia they are met in great areas. On the south shore of Lake Superior merchantable grades have been somewhat developed. Along the western slopes of the Sierra Nevada Mountains they are very important rocks.

THE CRYSTALLINE LIMESTONES AND DOLOMITES.

	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3 FeO	Insol.	Loss or H_2O
1.	99.51					0.29	0.20
2.	99.24	0.28					
3.	98.43	0.30		0.31		0.38	0.15
4.	98.21	2.35		0.15		0.35	
5.	98.00					0.57	1.63
6.	96.82	1.89		0.10		2.12	
7.	92.42	6.47		0.35		0.95	
8.	70.1	25.40				2.40	
9.	54.62	45.04	0.10	0.7			
10.	54.25	44.45				0.60	

1. Statuary Marble, Brandon, Vt. Quoted by G. P. Merrill, Stones for Building and Decoration, 417. 2. Marble, Carrara, Italy, *Idem*. 3. Marble, Knoxville, Tenn., *Idem*, also S, 0.014, Organic Matter, 0.068. 4. Cross-grained black and white mottled Marble, Pickens Co., Ga., locally called Creole; Geol. Surv. Ga., Bulletin I., 87. 5. White Marble, Rutland, Vt., see under No. 1. 6. Coarsely crystalline white Marble, Cherokee Quarry, Pickens Co., Ga., see under No. 4. 7. White Crystalline Limestone, Franklin Furnace, N. J., Geo. C. Stone, unpublished. 8. Crystalline Magnesian Limestone, Tuckahoe, N. Y., H. L., Bowker for Lime Co. 9. Crystalline Dolomite, so-called "Snowflake Marble," Pleasantville, N. Y., 16th Ann. Rep. Dir. U. S. Geol. Survey, Part IV., p. 468. 10. Crystalline Dolomite, white marble, Inyo Co., Calif., Ann. Rep. Calif. State Mineralogist, 128.

Comments on the Analyses. — The analyses do not differ essentially from those of unaltered limestones except in so far as the ones in the table are purer carbonates of lime and magnesia. The available analyses are of merchantable marbles, and in the nature of the case these are derived from very pure sedimentary limestones. They are interesting as illustrating a series from a rock that is almost chemically pure carbonate of lime to one in which the carbonate of magnesia reaches the values of typical dolomite. Comparison with the analyses of limestones earlier given, on p. 105, is recommended. It will be seen that in this case there is apparently

no change in gross composition because of metamorphism, but of course the relations of the silica and the bases are different. In the sedimentary limestones the silica is largely in the form of quartz and in combination with alumina forming hydrated silicates, such as kaolin. In the crystalline limestones it is largely in silicates of lime, magnesia and alumina, such as tremolite, pyroxene, phlogopite, etc., minerals whose formation has been one of the results of metamorphism. The percentages in the insoluble column do not therefore indicate pure silica. There may be even microscopic, barite crystals present.

Mineralogical Composition, Varieties.—The crystalline limestones and dolomites are metamorphosed forms of the sedimentary varieties earlier described. The change involved is, as the name implies, one of crystallization. Fossils, and to a large degree bedding planes, are destroyed and a more massive aggregate of calcite or dolomite crystals results. Such carbonaceous material as was originally present usually affords streaks of graphite which occasion dark veinings. They bring out the brecciation or flow-lines induced by the pressure from the mountain making upheavals usually attendant on the metamorphism. Other bituminous or ferruginous matter may yield pronounced colors of many hues.

If the original limestone has been an impure variety and has contained silica, alumina and iron oxides, as illustrated by the analyses on p. 105, these components have furnished the necessary materials for the various silicates that the metamorphism has caused to form. Tremolite is a common result, light-colored pyroxenes are not infrequent, and phlogopite and other micaceous minerals are the most abundant of all. Large quarries always show borders or streaks that are characterized by these minerals, and where the original limestone passed into shales or sandstones at its upper and under surfaces, these micaceous varieties are almost always met. For ornamental purposes, the included silicates serve to mar the stone, being, except in the case of micas, of greater hardness than the calcite.

Crystalline limestones form more or less extensive strata in the midst of other metamorphic rocks. Slates, phyllites, mica-schists and quartzites are their most common associates. The dolomites may have formed in many cases from pure calcareous limestones by

the infiltration of magnesian solutions, and by an exchange of a portion of the magnesia for a portion of the lime, as earlier referred to on page 106, but so many unaltered limestones are high in magnesia, that the change is not a necessary attendant of metamorphism.

Alteration.—Crystalline limestones are soluble rocks and weather with comparative facility. Where they occur in metamorphic belts they are invariably in the valleys, and are potent factors in determining the direction of the drainage lines. Where exposed for long periods they afford a coarse, crumbling sand or gravel, that is much used for roads in the borders of the Adirondacks and in western New England. The final stage is a mantle of residual clay from which the calcareous material has been largely leached.

Occurrence. — The crystalline limestones are frequent in our metamorphic districts. In the Appalachian belt they are of great areal and economic importance, and are largely quarried in Vermont, Massachusetts, New York, Pennsylvania and Georgia. In western Colorado they are strongly developed, and in the Sierras of California the same is true, Inyo County being a rather large producer of marble. The foreign mountainous and metamorphic districts exhibit enormous exposures. The great series of ranges which begin in the Pyrenees and extend through the Alps and the Carpathians to the Himalayas, have many famous quarries and ledges. The region of the "Dolomites" in the Tyrolese Alps is a district of especial richness. The Carrara marble of the Appenines, the Pentelic of Greece and the colored varieties from Northern Africa, indicate their presence in those regions.

THE OPHICALCITES, SERPENTINES AND SOAPSTONES.

Ophicalc.	$CaCO_3$	$MgCO_3$	CO_2	SiO_2	MgO	H_2O	FeO	Al_2O_3
1.	57.37	9.64	0.74	13.18	10.29	4.06	3.57	0.85
2.	23.85	22.28	1.97	22.42	18.74	6.43	4.30	
3.	7.65	10.98	1.78	36.53	28.08	8.63	6.49	

Serp.	SiO_2	MgO	H_2O	Al_2O_3	Cr_2O_3	Fe_2O_3	FeO	NiO	CaO
4.	44.14	42.97	12.89						
5.	43.87	38.62	9.55	0.31			7.17	0.27	0.02
6.	42.52	42.16	14.22			1.96			
7.	41.54	40.42	14.17	2.48			1.37	0.04	
8.	40.67	32.61	12.77	5.13			8.12		
9.	40.06	39.02	12.10	1.37	0.20		3.43	0.71	
10.	36.95	33.07	10.40			16.50			
11.	34.84	30.74	17.39	0.42	0.68	6.08	1.85	tr.	7.02

Soapst.	SiO_2	MgO	H_2O	Al_2O_3	Cr_2O_3	Fe_2O_3	FeO	NiO	MnO
12.	64.44	33.19	0.34	0.48			1.39	0.23	
13.	62.10	32.40	2.05				1.30		2.15
14.	62.00	33.1	4.9						

1. Ophicalcite, Oxford, Quebec, T. S. Hunt, Amer. Jour. Sci., March, 1858, 220. The analysis as cited is assembled from several partial analyses. 2. Ophicalcite, Brompton Lake, Quebec, *Idem*, p. 221. Original results recast as in No. 1. 3. Ophicalcite, Brompton Lake, Quebec, *Idem*, p. 222. Recast as before. 4. Theoretical serpentine, $H_4Mg_3Si_2O_9$. 5. Massive serpentine, Webster, N. C., F. A. Genth, Amer. Jour. Sci., II., xxxiii., 201. 6. Massive serpentine, Montville, N. J., E. A. Manice; Dana's Mineralogy, 1877, 467. 7. Serpentine, a metamorphosed sandstone, New Idria, Calif., W. H. Melville for G. H. Becker, in Monograph XIII., U. S. Geol. Surv., 110. 8. Serpentine, decomposed peridotite, Syracuse, N. Y., T. S. Hunt, Amer. Jour. Sci., Sept., 1858, 237. 9. Serpentine, Dublin, Harford Co., Md. Quoted by G. P. Merrill, Stones for Building and Decoration, 414. 10. Serpentine from peridotite, Presq' Isle, Mich., J. D. Whitney, Amer. Jour. Sci., II., xxviii., 18, also Na_2O, 0.97. 11. Serpentine from peridotite, Monte Diablo, Calif., W. H. Melville, Bull. Geol. Soc. Amer., II., 408, also Na_2O, 0.42, K_2O, 0.07. 12. Soapstone, Webster, Jackson Co., N. C., F. A. Genth, Minerals of North Carolina, p. 61. 13. Talc, Gouverneur, N. Y., Analysis quoted by C. H. Smyth, Jr., School of Mines Quarterly, July, 1896, p. 340. 14. Theoretical talc, $6MgO$, $5SiO_2$, $2H_2O$.

Comments on the Analyses. — The ophicalcites mark a passage from the dolomites to the serpentines. They are practically crystalline magnesian limestones or dolomites, which are mottled with inclusions of serpentine in varying amounts. The analyses begin with one that is over half calcite and over two thirds calcite and dolomite. The ratios of the remaining oxides are just about those required by serpentine. In the second the amount of serpentine has much increased, and in the third the carbonates have notably retreated. Under the serpentines, as compared with the theoretical mineral, No. 4, the succeeding analyses are all notably rich in iron. Except in the cases of Nos. 10 and 11, they are remarkably uniform considering their diverse origin. In No. 10 the SiO_2 drops, probably from the presence of magnetite, while in the last the pyroxene of the original peridotite has contributed considerable lime. In all these rocks Al_2O_3 is notably low. It is most abundant in No. 8, a serpentine that is derived from a rock with much augite. Chromium is a rather characteristic element in serpentines which result from basic igneous rocks, and nickel can be very generally detected on analysis. Lime practically fails except in No. 11. It should be appreciated that as a mineral, serpentine is a unisilicate, whereas talc is a bisilicate, and this explains the

much larger percentage of silica in the latter. The soapstones are fairly pure, aggregates of talc, as a comparison of Nos. 12 and 13 with No. 14 will indicate.

Mineralogical Composition, Varieties. — The ophicalcites are mottled rocks consisting of irregular or rounded masses of green serpentine embedded in white calcite and dolomite. The proportions of the constituent minerals are variable. The serpentine may be in small nodules a fraction of an inch in diameter or in large stringers and masses several feet across. This irregularity renders it difficult in quarrying to preserve a uniform grade. The stone is mottled green and white, and when uniform is a very beautiful one. The serpentine varies from dark green or almost black, to light clear shades, and has been derived in a number of cases, as has been shown by G. P. Merrill,* from original pyroxene crystals.

The ophicalcites are therefore in many cases alteration products from a crystalline limestone, that has been surcharged with pyroxenes, and this itself may probably be referred in most cases to an original siliceous, magnesian sediment, recrystallized by regional metamorphism.

Ophicalcites are also called ophiolites, serpentinous marbles and verd antique. The syllable "ophi," in all these words is derived from the Greek for serpent and ophicalcite means therefore a serpentinous limestone.

The serpentines are green or red aggregates of scales, fibers or massive individuals of the mineral serpentine. They display considerable variety of texture according to the characters of these components. Other minerals are not especially prominent. Grains of chromite or magnetite may be detected and garnets of the variety pyrope are sometimes well developed. Veinlets of calcite or of magnesian carbonates ramify through the rock in many exposures. Remains of the original olivine, pyroxene, or hornblende from which the serpentine has been derived may often be detected and biotite or some hydrated magnesian mica is not infrequent. The varieties of the mineral serpentine are numerous, but many of them are too rare to be serious rock-makers. Almost all serpentines have been formed by the alteration of basic igneous rocks,

* G. P. Merrill, *Amer. Jour. Sci.*, March, 1889; *Proc. U. S. Nat'l Museum*, XII., 595, 1890.

among which the pyroxenites and peridotites are the chief contributors. Hornblende schists also yield them and G. F. Becker has recorded the remarkable case of sandstones that pass into them in the Coast Ranges of California.

Soapstones, called also steatites, are chiefly talc as the analyses show. Quartz veinlets often run through the rock and scattered grains of quartz are not infrequent. Magnesian carbonates are likewise evident in many exposures. In the case of the Gouverneur beds of talc (see Anal. 13), C. H. Smyth has shown that the original minerals have been tremolite and enstatite, and that the beds occur in crystalline limestone, but it is a hard problem to determine from what the tremolite and enstatite have been derived. Two reasonable sources suggest themselves, either a siliceous dolomite, or a non-ferruginous, basic intrusive. The soapstones are not particularly abundant rocks but are of economic value where met. They are close relatives to the talc schists earlier cited.

Alteration.—The serpentinous rocks themselves are thoroughly altered derivatives from fresher anhydrous ones and in their further decomposition simply soften to incoherent dirt and clay. The more resistant, included minerals are thus set free, and as in the case of platinum and garnets they may be concentrated in gravel.

Distribution.—Ophicalcites are most abundant in Quebec, the northern Green Mountains and the foothills of the Adirondacks. The serpentines are especially notable on Staten Island, in southeastern Pennsylvania and the neighboring parts of Maryland, where the gabbros, as stated on p. 84, and their related rocks are abundant. They share in an important belt of these basic intrusives in North Carolina and Georgia. In the basic igneous rocks around Lake Superior they are occasionally met as alteration products. In the Coast ranges the serpentines are of very great importance, and in part are altered sediments. They are likewise common abroad, and in a minor capacity appear in many metamorphic districts. Soapstone is much less common, but is met in this country as a subordinate member in much the same regions as the serpentines and crystalline dolomites.

CHAPTER XII.

The Metamorphic Rocks, Concluded. The Rocks Produced by Atmospheric Weathering. The Determination of the Metamorphic Rocks.

Introduction. — It is a matter of common observation that outcrops of rocks and loose boulders are always more or less decomposed and broken down or "weathered" for a greater or less distance below their surfaces. This may not be serious enough to prevent the accurate recognition of the rock, and usually within the area once covered by the great ice sheet of the Glacial Period it is not, because the moving ice has ploughed away all loose and decomposed materials, but south of the terminal moraine, and above all in the tropics, the decomposition is excessive and may produce to a depth of a hundred feet or more a mass of alteration products that give of themselves slight, if any, clue to their originals. This is a common experience in the Southern States, where, as well as in Central and South America, the indefinite character of the surface rock throws great difficulties in the way of accurate geological mapping. So difficult at times is the determination of the country rock, that, for example, during field work in Brazil, O., A. Derby has felt compelled to resort to the panning out of the surface materials with a gold-seeker's pan in order, by concentrating the heavy but small and undecomposed, accessory minerals, such as zircon, titanite, monazite, xenotime, apatite and others, to get from their characteristic associations some clue to the original rock. Many travelers have noted the brilliant colors of the soils of latitudes toward the equator and the comparatively somber tones of those toward the poles.

These products of weathering are so widespread, therefore, and so individual that a few pages have been reserved for their particular mention. Special names for them have been suggested at various times. The oldest one and the one most current is *laterite*. The word means brick earth and was originally applied to the red or brown iron-stained surface soils occurring in the tropical lands, and

derived by direct decomposition from the country rock in place. It has been applied in later years, however, to all sorts of these surface soils from whatever rocks derived, and whether colored red or not. G. F. Becker, of the U. S. Geological Survey, has recently (1895) proposed *saprolite*,* a word meaning literally rotten rock, as "a general name for thoroughly decomposed, earthy, but untransported rock." This is practically the modern use of laterite, although it is broader than the latter's original application. The U. S. Geological Survey in the invaluable series of atlas sheets now being issued employs the term *surficial*, *i. e.*, surface rocks, as a general designation for these untransported products of decomposition. We also often speak of residual clay as was done on pp. 100 and 102 for the less soluble, aluminous residues left behind in the removal of the more soluble portions of limestones.

The general scope and application of these names having been set forth, a brief consideration will be given to the mineralogical processes of change that have produced them from several of the commoner groups of rocks.

The chief causes of this superficial breaking down or "degeneration," as it has been aptly called by G. P. Merrill,† are, the chemical action of rain and ground-waters, especially when charged with carbonic acid or other dissolved matter; organic life, both vegetable and animal, operating through the agency of the organic acids produced by their living processes or by their decomposing remains; and the mechanical disintegration produced by changes of temperature, by the freezing of water and by swelling from hydration or from some of the chemical or mineralogical changes among those referred to above. Although having no connection with these atmospheric processes, yet hot springs and allied exhalations from dying volcanic energy bring about closely similar results and are able to change great sheets of volcanic rock to brilliantly variegated masses of clay and kaolin. At the Falls of the Yellowstone River, in the National Park, these are wonderfully and impressively displayed, more than a thousand feet of rhyolite having been changed practically to kaolin.

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*Gold Fields of the Southern Appalachians, *16th Ann. Rep. Dir. U. S. Geol. Survey*, 3, 289, 1895.

† *Bulletin of the Geological Society of America*, VII., 378.

Under the action of the chemical agents the more easily soluble elements are removed or put in such relations to one another as to facilitate their rearrangement in new and secondary combinations. In the rocks composed of silicates the most vulnerable oxides are lime, magnesia, potash and soda. Iron oxides also suffer extensively, but the ferric form is sometimes very resistant. Silica yields more or less, especially to the alkaline solutions from the potash and soda referred to above. Alumina, on the whole, is least readily attacked of all, and is usually the one that furnishes the best basis of comparison between analyses of altered and unaltered materials.

Among the igneous and metamorphic rocks, open or porous varieties naturally suffer more than compact and finely crystalline ones. Rocks high in the bases that are most readily attacked chemically, are easier victims than those especially rich in the resistant ones. Basic rocks, therefore, with their high percentages of lime and magnesia and their relatively low silica, suffer especially, whereas, granites and related gneisses are much more stubborn subjects, the large amount of quartz in them furnishing a very resistant component.

Granites, syenites, acid diorites and their corresponding porphyritic types alter especially through the feldspathic member present. The constituent quartz is but slightly affected, and the dark silicates are not present in sufficiently large amounts to be very serious factors. The resulting product is a kaolinized or clayey mass through which are distributed quartz grains, and which is more or less stained by the hydrated oxide of iron that is yielded to some extent by the dark silicates. The characteristic products of the latter are also present in small amounts, but are more extensively mentioned subsequently. The exposed ledges furnish loose pieces that often weather in concentric shells and simulate rounded, waterworn boulders. The next result is a large contribution of clay and sand to sedimentary or eolian deposits, it may be at a great distance.

In the basic igneous or metamorphic rocks the dark ferro-magnesian and aluminous silicates are in excess, and in decomposition their peculiar products predominate. The distinctively magnesian ones yield serpentine, the aluminous change to chlorite. Both these minerals are prevailingly green, and dark green, surficial

rocks result. The abundance of iron in them leads to the formation of very rusty outcrops.

In the case of limestone, the lime and magnesia are dissolved away, while the alumina, silica and iron oxides remain behind in the mantle of impure residual clay already referred to. The other sedimentary rocks suffer especially from mechanical processes, although chemical changes are not lacking among them, for, as remarked on page 145 regarding analysis No. 1, of page 97, during the breaking up considerable leaching may result that leads to the production of nearly chemically pure quartz sand.

The mechanical and associated, chemical breaking down of rocks tends to place them in more favorable conditions for further chemical alterations, and for erosion and removal.

All the changes in the weathering of rocks have been well described by M. E. Wadsworth as "resulting from the general dissipation and degradation of the potential energy of the constituents of the earth's crust in the universal passage of matter from an active state towards a passive and inert condition."*

The Determination of the Metamorphic Rocks.

The rocks resulting from contact metamorphism are rather of local interest, than of wide, areal distribution. The spotted schists and slates, and the hornstones are readily recognized by a practiced observer. The crystalline limestones even when charged with silicates may closely resemble the products of regional metamorphism. In dealing with the latter, familiarity with well characterized types is the safest guide. The gneisses are at once apparent from their laminated character and granitoid texture. Transition members between them and the mica-schists on the one hand, and the hornblende-schists on the other, may cause hesitation as to which group they belong. The finely laminated ones are certainly members of the schists, those with prevailing mica belonging with the mica-schists, those with prevailing hornblende, with the hornblende-schists. Again as the fineness of the lamination or foliation increases, the schists pass into the phyllites and slates, that are easily recognized. The quartzites likewise present

* The Theories of Ore Deposits, *Proc. Bost. Soc. Nat. Hist.*, Vol. XXIII., p. 202, 1884.

little difficulty as they are practically hard sandstone. The crystalline limestones and dolomites are only to be distinguished by the ease or difficulty of obtaining effervescence. The ophicalcites look like no other rocks, and the serpentines and soapstones are also at once apparent. The soapy feel of all these magnesian rocks aids in their recognition. There are, of course, rare and obscure, metamorphic rocks that cause trouble, but, just as in the case of the finely crystalline igneous rocks, they are best referred to someone familiar with the use of the microscope.

The Study of the Metamorphic Rocks.

The metamorphic rocks present some of the most elusive and difficult problems of geology, but in later years the combination of exact determinations of minerals by means of the microscope and of chemical analyses has been illuminating. Strong efforts have been made to express by accurate chemical equations the reactions which have taken place in the re-crystallization of minerals, both at and below the surface of the earth. President C. R. Van Hise, of the University of Wisconsin, has brought together a vast number of these in the Monograph on Metamorphism No. XLVII. of the U. S. Geological Survey. The book is encyclopedic as a work of reference. With the author we may regard the outer portion of the earth down to the level of standing water, as the zone or belt of weathering or oxidation. Within it, rocks and minerals break down, as just described under the products of weathering. The results and processes of the zone may be called katamorphic in reference to the breaking *down*. Such of the dissolved matter as does not run off, sinks, and passing to the deeper zone beneath the ground-water shares in the production of new minerals under the influence of heat and pressure. We thus have the deeper "building-up" or anamorphic belt, called also the zone of cementation. Fragmental rocks are changed from incoherent particles to solid masses by the deposition of new material. These terms have all come into wide use in later years so that it is well for the student to become familiar with them. Others have further sought to classify the component minerals with regard to depth of formation. Professor F. Becke, now of Vienna, suggested the interesting plan of classifying the minerals into plus and minus

groups, according as their densities have increased or decreased over the densities of what might be considered their components. The increase or decrease is determined by the aid of certain numbers expressive of "molecular volumes." Thus quartz, SiO_2, has a molecular weight of 60, and a sp. gr. of 2.66. If we divide the former by the latter (60 ÷ 2.66) we obtain 22.56 expressive of its molecular volume. Corundum, Al_2O_3 has a molecular weight of 102 and a sp. gr. of 4. Its molecular volume is therefore 25.5. Now there are three different metamorphic minerals produced by the union of Al_2O_3 and SiO_2 with a molecular weight of 162, viz., andalusite, sp. gr. 3.20; molecular volume, 50.6; sillimanite, sp. gr. 3.24; molecular volume, 50, and cyanite, sp. gr. 3.6; molecular volume 45. The sum of the molecular volumes of quartz and corundum is 48.06, so that if we imagine the combination of the two to Al_2O_3,SiO_2, there is a gain in molecular volume, respectively in andalusite and sillimanite of 2.54 and 1.94; whereas in cyanite there is a loss of 3.06. We would perhaps infer with reason that cyanite forms under greater pressure than the other two, and therefore at greater depth. By taking the metamorphic minerals comprehensively and interpreting them in this way with regard to depth, some interesting inferences may be drawn.

The metamorphism of ancient sediments varies greatly in degree. The history of some, such as slates and quartzites, is not so difficult to trace, but where we meet others, very old, of former deep burial, and penetrated through and through with igneous rocks, the geologist finds it difficult to draw the line between metamorphosed sediments and intrusive masses. Recrystallization from the influence of magmatic waters, the so-called "juice of the magma"; "digestion or half-digestion" by the igneous rock; thorough penetration of the sediments by igneous substance, yielding injected gneisses; and similar processes must be invoked. The rocks of the Adirondacks and of Quebec, and those of Sweden and Finland have driven observers to these conclusions.

When dealing with metamorphic districts the student fresh from the laboratory must be prepared for many obscure phenomena, about which the best informed and most experienced workers are not yet entirely clear.

Contact.			Regional.						Products of Weathering.
Internal.	External.		Gneisses corresponding in Mineralogy to the Granitoid Igneous Rocks. A few others.		Crystalline Schists.		Quartzites and Slates.	Crystalline Limestones.	Ophicalcites, Serpentines, Soapstones.	
			Derived from Igneous.	Derived from Sedimentary.						
Glasses.	Conglomerates and sandstones.	Effects relatively slight. Quartzites. (Buchite.)	Granite gneiss or gneiss proper.	Granitic gneiss or gneiss proper.	Mica.	Mica schists often with garnet, staurolite, etc. Phyllites.	Quartzites (Quartz schists).	Marbles often with Mica, Tremolite, etc.	Serpentinous marble or ophicalcite, verd-antique.	Residual soils.
Felsites.	Shales and clays.	Andalusite hornfels. Lime-silicate hornfels. Spotted slates.	Syenite gneiss. Diorite gneiss. Gabbro gneiss.	Syenitic gneiss. Dioritic gneiss, etc. Conglomerate gneiss.	Hornblende.	Hornblende schists often with garnet, epidote, scapolite. Amphibolites.	Graywackes. Slates (Phyllites).		Serpentine often with chromite, garnet, etc.	Subsoil.
Porphyries.	Limestones.	Garnet, diopside, vesuvianite, epidote, wollastonite, scapolite, ores.	Pyroxenite gneiss.	Gneisses with a prominent mineral, such as biotite-gneiss, etc.	Various schists.	Chlorite schist or green schists. Talc schists. Eclogite. Glaucophane schists. Quartz schists.		Dolomites often with Mica, Tremolite, etc.	Soapstone or steatite.	Saprolites in general. Laterites especially from basalt.
	Coals.	Natural coke. Anthracite.	Peridotite gneiss.							

CHAPTER XIII.

The Re-calculation of the Chemical Analyses of Rocks.*

The importance of chemical analyses of rocks in general and of igneous varieties in particular has only been properly appreciated within the last ten years. It is indeed true that in the time of Abich and Bunsen in the fifth and sixth decades of the last century much attention was given to this branch of investigation, and that the work and influence of the latter made available many results; but interest languished with the passing away of faith in his two fundamental magmas — the normal-trachytic and the normal-pyroxenic — in the igneous rocks, and the analyses which were subsequently made and recorded were either prompted by their practical applications, or were merely intended to give a general idea of the composition of the rock in question. They were seldom employed for close mineralogical computations. Those geologists who considered the subject at all, believed that analyses were so variable and were so largely a function of the sample taken, that they might differ greatly if the materials were derived merely from opposite ends of a hand-specimen. They therefore gave them comparatively small attention. Even when analyses were to a certain extent recast, as for instance in the *Reports of the Survey of the Fortieth Parallel*, only the percentages of oxygen in the SiO_2, Al_2O_3, Fe_2O_3, FeO, etc., were deducted from the total percentages of the oxides and were used to calculate the so-called "oxygen ratio"; that is, the continued ratio of the percentage of oxygen combined with the silicon, to that combined with the monad and dyad bases, to that combined with the triads. The quotient obtained by dividing the sum of the last two by the first was called the oxygen quotient and was esteemed to be characteristic of the several groups of igneous rocks.

The following ranges of oxygen quotients would not be far from the truth. It is well to add that the higher the silica the lower the

* This chapter in practically its present form originally appeared in the *School of Mines Quarterly*, November, 1900, 75.

quotient. Ultra-basic rocks would run even higher than the values here given.

Rhyolites — Granites	.175–.350
Trachytes — Syenites	.350–.575
Dacites — Quartz-diorites	.275–.350
Andesites — Diorites	.350–.500
Basalt — Gabbro	.540–.675

To a certain degree these values are characteristic, and being in each case a single number which summarizes a whole analysis they are more easily employed than are the equally characteristic percentages of several oxides, but, after all is said, the contrasts are based upon no very fundamental or at least no very definite principle, and they give no clew to the mineralogy of the rock. The same quotients may be obtained with widely differing aggregates of minerals and from very dissimilar rocks.

From the introduction of microscopic methods of investigation up to approximately 1890, the energies of practically all students of the subject were devoted to observing and recording mineralogical and textural details and the subject of chemical composition received but slight attention. It was revived, however, toward the close of the eighties by W. C. Brögger, then in Stockholm, and in the course of time has received wide recognition and employment from many others.

Petrographers are now accustomed to recast an ordinary chemical analysis by dividing the several percentages by the molecular weights of the corresponding molecules, so as to obtain a series of numbers, which are called the "molecular proportions" or "molecular ratios." These quantities indicate the relative numbers of the several molecules in the rock magma, and in that respect are more significant than are the percentages. Using the molecular proportions as fundamentals, curves or diagrams of various sorts can be plotted, which will indicate in a graphic way the variations in composition of a series of igneous rocks in a single district, or the variations in a single family, the specimens coming from various districts. Many interesting conclusions may be drawn and many characteristics shown. The molecular compositions of the common rock-making minerals are now quite accurately determined

and understood, and using them it is often possible to calculate from the molecular proportions furnished by a rock analysis, the percentages of the several minerals in the rock. The calculations are usually checked in a general way by a study of thin sections.

The commoner rock-making minerals and their molecular compositions are given below in the tables, to which reference may be made in following the accompanying illustrations, but it may be remarked that petrographers are accustomed to regard minerals of complex compositions as made up of combinations in varying proportions of simple molecules. Thus labradorite is a lime-soda feldspar, but it is conceived to be formed by a combination in the proper proportions of the albite molecule, $Na_2O,Al_2O_3,6SiO_2$, with the anorthite molecule $CaO,Al_2O_3,2SiO_2$. Hypersthene is a silicate of magnesia and ferrous oxide, but we think of it as a combination of MgO,SiO_2 with FeO,SiO_2. Olivine is also a silicate of magnesia and ferrous oxide, and is regarded as a combination of $(MgO)_2SiO_2$ with $(FeO)_2SiO_2$.

In a recent joint report by W. H. Weed and L. V. Pirsson,* the latter presents recalculated analyses of a large number of igneous rocks. The following example is selected from pp. 466–467. A syenite was gathered at the Wright and Edwards mine, Barker, Mont., and was analyzed by W. F. Hillebrand of the U. S. Geological Survey. A number of minor and relatively unimportant determinations were made, in addition to those here quoted, as for instance TiO_2, H_2O, CO_2, BaO and SrO, all amounting to 1.50. In the citation below, the molecular proportions are given under the respective percentage values.

SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	P_2O_5	Cl	Total.
64.64	16.27	2.42	1.58	1.27	2.65	4.39	4.98	.37	.05	98.62
1.077	.158	.015	.022	.031	.047	.070	.053	.002	.0014	

From an examination of thin sections with the microscope it was observed that the minerals in the rock were the following. The quartz, it may be remarked, was inconspicuous, so that the rock is called a syenite, the total silica being at the same time below the percentages of a possible feldspar, albite.

* Geology of the Little Belt Mountains, Montana, by W. H. Weed, with a report on the Petrography by L. V. Pirsson. *20th Ann. Rep. Dir. U. S. Geol. Survey*, III., 257. The analysis is taken from p. 466.

Orthoclase, K_2O, Al_2O_3, $6SiO_2$

Plagioclase { Albite, Na_2O, Al_2O_3, $6SiO_2$
Plagioclase { Anorthite, CaO, Al_2O_3, $2SiO_2$

Hornblende { MgO, SiO_2
Hornblende { CaO, SiO_2
Hornblende { FeO, SiO_2

Magnetite, Fe_2O_3, FeO

Quartz, SiO_2.

From an inspection of these formulas it is evident that all the K_2O is in the orthoclase; all the Na_2O is in the albite; all the remaining Al_2O_3 is in the anorthite and requires an equivalent number of molecules of CaO. The remaining CaO is in the hornblende and apatite. The apatite can be calculated on the basis of the P_2O_5. All the MgO is in the hornblende. All the Fe_2O_3 is in the magnetite and an equivalent number of molecules of FeO are required by it. The remainder of the FeO is in the hornblende. The excess of SiO_2 then remains for the quartz. The molecular proportions are hereafter employed as whole numbers.

	Orthoclase.	Albite.	Anorthite.	Excess.
K_2O	53			none
Na_2O		70		none
CaO			35	12
Al_2O_3	53	70	35	none
SiO_2	318	420	70	269

The total CaO is 47; CaO in anorthite 35; therefore of the CaO 12 remain for the apatite and hornblende. The expanded formula for apatite is $9CaO$, $CaCl_2$, $3P_2O_5$, but from this expression we are never to infer that the $CaCl_2$ exists as such in the mineral. The Ca in the $CaCl_2$ has been weighed as CaO. Having therefore abstracted the necessary CaO for the apatite the residue will go to the hornblende as shown in the next tabulation, which also embraces all the remaining minerals.

	Apatite.	Hornblende.			Magnetite.	Quartz.
P_2O_5	2					
Cl_2	.7					
CaO	6.7	5.3				
MgO			31			
FeO				7	15	
SiO_2		5.3	31	7		225.7
Fe_2O_3					15	

In order to turn these results into percentages of the minerals in the rock, we multiply the several molecular proportions by the respective molecular weights.

Thus—Magnetite,	.015	Fe_2O_3	× 160 = 2.42		
	.015	FeO	× 72 = 1.08	Total,	3.50
Hornblende,	.031	MgO	× 40 = 1.24		
	.031	SiO_2	× 60 = 1.86		
	.005	CaO	× 56 = .28		
	.005	SiO_2	× 60 = .30		
	.007	FeO	× 72 = .50		
	.007	SiO_2	× 60 = .42	Total,	4.60
Anorthite,					9.73
Albite,					36.68
Orthoclase,					29.46
Quartz,					13.54
Apatite,					1.10
Grand Total,					98.61

In order to raise these individual percentages so that they will make an even hundred, they should each be increased about 1.5 per cent.

Magnetite,	3.55
Apatite,	1.11
Hornblende	4.66
Anorthite,	9.86
Albite,	37.22
Orthoclase,	29.90
Quartz,	13.70
	100.00

The above values differ slightly from those obtained by Professor Pirsson, because apatite was not reckoned by him, the lime being attributed to the hornblende and anorthite.

In one respect the numerical labor may be shortened. Thus the percentage of orthoclase is $.053K_2O \times 94 + .053Al_2O_3 \times 102 + 6(.053SiO_2) \times 60$, an expression which may be factored into $.053\,[94 + 102 + (6 \times 60)]$. This latter is merely the molecular weight of orthoclase multiplied by the molecular proportion of the K_2O, the oxide which gave us the clue to the original calculation of the orthoclase. For this purpose the molecular weights of the several rock-making minerals are later given.

If the albite molecules were all combined with the anorthite ones in order to yield a plagioclase — the relative amounts of each in

the plagioclase would be proportional to the sums of the molecular proportions of the component oxides, as given in the tabulation, p. 152; *i. e.*, albite, 70 + 70 + 420 = 560 and anorthite 35 + 35 + 70 = 140. This would be Ab_4An.* But some of the albite is in the orthoclase. Pirsson found by determination of the optical properties of the plagioclase that it was approximately Ab_2An. Half the albite molecules were therefore in the orthoclase or present in microperthite. From these deductions we can calculate the ratio of alkali-feldspar to soda-lime feldspar, viz. :

424 Or + 280 Ab = 704 Alkali feldspar.
280 Ab + 140 An = 420 Soda-lime feldspar.

This ratio 704 : 420 is almost exactly 5 : 3. One can readily appreciate the accuracy with which a result of this character will enable us to classify rocks as orthoclase or alkali feldspar rocks and as plagioclase rocks.

In the actual performance of these recalculations, the mineralogical composition of the rock is not always so simple as in the case cited. For instance, when biotite is present with orthoclase, one cannot say how much potash and alumina belong with each; and if hornblende is also present, the distribution of the magnesia and iron oxide presents difficulties. In such cases it may be necessary to separate and analyze one of the minerals in order to furnish the clue, by which the analysis may be unraveled. When, at some future day the necessary data shall have been accumulated, there is little question that rocks of similar textures will be classified and defined on the basis of their percentages of the several component minerals.

The molecular compositions of the more important rock-making minerals are here given together with their molecular weights. Next a series of tables similar to tables of logarithms is appended by means of which molecular proportions can at once be looked up and set down for all percentages of the more abundant oxides which are likely to occur in the usual run of analyses. It is hoped that by their use the recalculation of analyses may be facilitated and more often performed.

* In the customary abbreviations Ab means albite, An, anorthite, and Or, orthoclase, as explained on page 5.

Mineral.	Formula	Molecular Weight.
Quartz,	SiO_2	60
Feldspars.		
Orthoclase,	$K_2O, Al_2O_3, 6SiO_2$	556
Albite,	$Na_2O, Al_2O_3, 6SiO_2$	524
Anorthite,	$CaO, Al_2O_3, 2SiO_2$	278
Feldspathoids.		
Nephelite,	$Na_2O, Al_2O_3, 2SiO_2$	284
Leucite,	$K_2O, Al_2O_3, 4SiO_2$	436
Melilite,	$12CaO, 2Al_2O_3, 9SiO_2$	1416
Analcite,	$Na_2O, Al_2O_3, 4SiO_2 + 2H_2O$	440
Sodalite,	$3[Na_2O, Al_2O_3, 2SiO_2] + 2NaCl$	969
Haüynite,	$3[Na_2O, Al_2O_3, 2SiO_2] + 2CaSO_4$	1124
Noselite,	$3[Na_2O, Al_2O_3, 2SiO_2] + 2Na_2SO_4$	1136
Micas.		
Muscovite,	$(K,H)_2O, Al_2O_3, 2SiO_2$	
Biotite,	$2[(H,K)_2O, (AlFe)_2O_3.2SiO_2]$ $2(Mg,Fe)O, SiO_2$.	
Amphiboles and Pyroxenes contain in the different varieties different proportions of the molecules here given:	MgO, SiO_2	100
	FeO, SiO_2	132
	CaO, SiO_2	116
	$(MgFe)O, (Al,Fe)_2O_3, SiO_2$	
	$Na_2O, Fe_2O_3, 4SiO_2$	462
Olivine,	$(MgO)_2, SiO_2$	140
	$(FeO)_2, SiO_2$	204
Magnetite,	FeO, Fe_2O_3	232
Apatite,	$9CaO, 3P_2O_5, CaCl_2$	1041
	$9CaO, 3P_2O_5, CaF_2$	1008

In the group consisting of haüynite and noselite (often called respectively haüyne and nosean) neither mineral occurs pure, of the formula given, because the two molecules always replace each other — the combination rich in lime being called haüynite, that rich in soda, noselite. In cases where as in muscovite, biotite and one of the pyroxenes, two elements, such as K and H, Al and Fe, or Mg and Fe replace each other in indefinite amounts, no molecular weight can be calculated. We must then assume separate and relatively simple molecules; for instance in muscovite K_2O, Al_2O_3, $2SiO_2$ and H_2O, Al_2O_3, $2SiO_2$. It does not follow however that these are known in nature.

As stated on the previous page, when the same oxide is present in two or more minerals, as for instance K_2O in orthoclase, biotite, and muscovite, or MgO in pyroxene and biotite, or in amphibole and biotite, we may find difficulty in allotting the proper amounts to each. Our only course is then to estimate from a study of the

hand-specimen or thin section relative proportions of these minerals in the rock and assume a partition accordingly. Where these minerals are in large quantities the possible error is objectionable, but where one or the other is in small amount the error is not a very serious matter. In all such cases the whole method of recasting fails because we have too many unknown quantities and too few equations for solution. Our only recourse then is either to separate the special mineral in question and analyze it, or else to assume standard minerals as is done in the quantitative scheme of classification outlined below, but the standard minerals themselves may not and often do not exist in the rock.

The other difficulty, referred to in the second paragraph above, is inevitable, when as in the case of muscovite, biotite, the pyroxenes, amphiboles and olivine, one base may be replaced to a varying degree by another of isomorphous character, as K_2O and H_2O in muscovite, MgO and FeO in all the ferromagnesian ones. Then we do not know how much of each to use. We must in consequence assume some ratio. Efforts are being made by the separation and analysis of the minerals which create these difficulties to discover and establish certain types which may be regarded as fairly characteristic and uniformly present in rocks of related chemical composition. The requisite data for generalizations are hardly yet at command, but the outlook is encouraging.

In the recasting of basic rocks containing both pyroxene and olivine, or amphibole and olivine, we first calculate tentatively, as if only pyroxene were present. If there is then too little SiO_2 to satisfy the MgO and FeO on the unisilicate ratio, it is necessary to distribute it between unisilicates and bisilicates, the latter of course taking twice the bases for the same silica. It is necessary also to assume or to know the ratio of MgO: FeO in both unisilicates and bisilicate. This being true and letting

a = FeO, b = MgO, c = SiO_2 available, all being known quantities;

x = the silica in the unisilicates, being also equal to the MgO + FeO in the same

$c - x$ = the silica in the bisilicates, being also half the MgO + FeO in the same.

Then

$$2(c - x) + x = a + b, \quad x = 2c - (a + b)$$

Having now the distribution of the silica, we can assign to its two portions, our bases according to the assumed or known ratios.

In the following tables the oxides are arranged in the order suggested by H. S. Washington in the *American Journal of Science*, July, 1900, p. 59. It is the most convenient and significant one for petrographers and it emphasizes the most important features, even if it separates oxides of like chemical properties, such as SiO_2 and TiO_2, Al_2O_3, Fe_2O_3 and Cr_2O_3, etc. In using the table the units of percentage are in the left line, the decimals then follow horizontally to the right as in logarithms, but by a proper use of the decimal point the same values will answer for tenths or multiples by ten, of these percentages.

Following the tables and on p. 176, the factors are summarized for turning molecular proportions into percentages. The factors are usually the molecular weights and are necessarily so whenever the entire formula of a mineral can be factored into a whole-number multiple of any one component. In the cases of melilite, sodalite, hauynite, noselite, and apatite this cannot be done. In each of these cases the formula has been reduced to an expression involving the key oxide as a unit, and the corresponding factor has been calculated. Thus melilite, $12CaO, 2Al_2O_3, 9SiO_2$ becomes $CaO, \frac{1}{6}Al_2O_3, \frac{3}{4}SiO_2$ giving in this form a molecular weight of 118, by which factor the total molecular proportion of the CaO obtained for this mineral in recasting may be immediately multiplied in order to get the percentage of the mineral itself.

In a similar way the molecules of the other minerals cited have been treated. While these recalculations are simple in themselves yet they have an element of the obscure and the elusive. Probably all teachers have discovered the ease with which the inexperienced become confused.

Having determined the percentages by weight of the several component minerals in a rock, it is sometimes desirable to express their percentages by volumes. This may be done if the weight-percentage of each mineral is divided by its specific gravity. The several quotients must then be added up to a total, which when divided into each of the quotients in turn will give its volume-percentage. In such recasting it is somewhat surprising to the inexperienced to note what a relatively small percentage by volume, a

relatively high percentage by weight of a heavy mineral involves. Calculations along these lines are sometimes of much importance in the investigations of lean or disseminated ores. Thus those lean magnetites which can only be treated by crushing and magnetic concentration can be expressed in terms of much greater significance than the mere chemical analyses. While ores of this type only involve normal rock-making minerals, yet galena and blende in limestone, or any others regarding whose composition and specific gravity we have the necessary data can be treated in a precisely similar way.

When the recasting of analyses can be carried out it forms a good check on the accuracy of the analytical work, because if the percentage results do not actually or approximately afford some reasonable combination of minerals, errors have obviously been made.

By a series of assumptions regarding the composition of some of the minerals which make trouble in the recasting, Messrs. Cross, Iddings, Pirsson and Washington have developed a series of so-called "standard" minerals into which for purposes of quantitative classification any analysis of an igneous rock can be broken up. This computed mineralogical aggregate is called the "norm." It may or may not differ seriously from the actual composition called the "mode," but once the norm is calculated, any rock of which a good analysis has been made, can be quickly placed in the quantitative scheme of classification. The methods and the scheme itself are too complicated to be described here and reference should be made to the original works.* While admirably adapted for the purposes of the investigator into the chemical relations of rocks and magmas, yet for the reasons that it makes texture play the most subordinate part of all in its determinations; that it requires a chemical analysis for its application in new cases; and that it deals with assumed and often non-existent minerals instead of those really present; it cannot be used by the ordinary observer or the field geologist.

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*Cross, Iddings, Pirsson and Washington, Quantitative Classification of Igneous Rocks, Chicago, 1903. H. S. Washington, Chemical Analyses of Igneous Rocks, Professional Paper No. 14, U. S. Geological Survey. J. P. Iddings, Chemical Composition of Igneous Rocks, expressed by means of diagrams, etc. Professional Paper No. 18, do., do. G. I. Finlay, The calculation of the norm in igneous rocks. *Jour. Geol.*, XVIII., 58, 1910. Best guide for beginners.

Silica, SiO_2. Molec. Weight 60. Log. 1.778151.

	0	1	2	3	4	5	6	7	8	9
30	.500	.501	.503	.505	.506	.508	.510	.511	.513	.515
31	.516	.518	.520	.521	.523	.525	.526	.528	.530	.531
32	.533	.535	.536	.538	.540	.541	.543	.545	.546	.548
33	.550	.551	.553	.555	.556	.558	.560	.561	.563	.565
34	.566	.568	.570	.571	.573	.575	.576	.578	.580	.581
35	.583	.585	.586	.588	.590	.591	.593	.595	.596	.598
36	.600	.601	.603	.605	.606	.608	.610	.611	.613	.615
37	.616	.618	.620	.621	.623	.625	.626	.628	.630	.631
38	.633	.635	.636	.638	.640	.641	.643	.645	.646	.648
39	.650	.651	.653	.655	.656	.658	.660	.661	.663	.665
40	.666	.668	.670	.671	.673	.675	.676	.678	.680	.681
41	.683	.685	.686	.688	.690	.691	.693	.695	.696	.698
42	.700	.701	.703	.705	.706	.708	.710	.711	.713	.715
43	.716	.718	.720	.721	.723	.725	.726	.728	.730	.731
44	.733	.735	.736	.738	.740	.741	.743	.745	.746	.748
45	.750	.751	.753	.755	.756	.758	.760	.761	.763	.765
46	.766	.768	.770	.771	.773	.775	.776	.778	.780	.781
47	.783	.785	.786	.788	.790	.791	.793	.795	.796	.798
48	.800	.801	.803	.805	.806	.808	.810	.811	.813	.815
49	.816	.818	.820	.821	.823	.825	.826	.828	.830	.831
50	.833	.835	.836	.838	.840	.841	.843	.845	.846	.848
51	.850	.851	.853	.855	.856	.858	.860	.861	.863	.865
52	.866	.868	.870	.871	.873	.875	.876	.878	.880	.881
53	.883	.885	.886	.888	.890	.891	.893	.895	.896	.898
54	.900	.901	.903	.905	.906	.908	.910	.911	.913	.915
55	.916	.918	.920	.921	.923	.925	.926	.928	.930	.931
56	.933	.935	.936	.938	.940	.941	.943	.945	.946	.948
57	.950	.951	.953	.955	.956	.958	.960	.961	.963	.965
58	.966	.968	.970	.971	.973	.975	.976	.978	.980	.981
59	.983	.985	.986	.988	.990	.991	.993	.995	.996	.998
60	1.000	1.001	1.003	1.005	1.006	1.008	1.010	1.011	1.013	1.015
61	1.016	1.018	1.020	1.021	1.023	1.025	1.026	1.028	1.030	1.031
62	1.033	1.035	1.036	1.038	1.040	1.041	1.043	1.045	1.046	1.048
63	1.050	1.051	1.053	1.055	1.056	1.058	1.060	1.061	1.063	1.065
64	1.066	1.068	1.070	1.071	1.073	1.075	1.076	1.078	1.080	1.081
65	1.083	1.085	1.086	1.088	1.090	1.091	1.093	1.095	1.096	1.098
66	1.100	1.101	1.103	1.105	1.106	1.108	1.110	1.111	1.113	1.115
67	1.116	1.118	1.120	1.121	1.123	1.125	1.126	1.128	1.130	1.131
68	1.133	1.135	1.136	1.138	1.140	1.141	1.143	1.145	1.146	1.148
69	1.150	1.151	1.153	1.155	1.156	1.158	1.160	1.161	1.163	1.165
70	1.166	1.168	1.170	1.171	1.173	1.175	1.176	1.178	1.180	1.181
71	1.183	1.185	1.186	1.188	1.190	1.191	1.193	1.195	1.196	1.198
72	1.200	1.201	1.203	1.205	1.206	1.208	1.210	1.211	1.213	1.215
73	1.216	1.218	1.220	1.221	1.223	1.225	1.226	1.228	1.230	1.231
74	1.233	1.235	1.236	1.238	1.240	1.241	1.243	1.245	1.246	1.248
75	1.250	1.251	1.253	1.255	1.256	1.258	1.260	1.261	1.263	1.265
76	1.266	1.268	1.270	1.271	1.273	1.275	1.276	1.278	1.280	1.281
77	1.283	1.285	1.286	1.288	1.290	1.291	1.293	1.295	1.296	1.298
78	1.300	1.301	1.303	1.305	1.306	1.308	1.310	1.311	1.313	1.315
79	1.316	1.318	1.320	1.321	1.323	1.325	1.326	1.328	1.330	1.331

Alumina, Al_2O_3, Molec. Weight 102. Log. 2.008600.

	0	1	2	3	4	5	6	7	8	9
0	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
1	.010	.011	.012	.012	.013	.014	.015	.016	.017	.018
2	.020	.021	.021	.022	.023	.024	.025	.026	.027	.028
3	.030	.031	.031	.032	.033	.034	.035	.036	.037	.038
4	.040	.041	.041	.042	.043	.044	.045	.046	.047	.048
5	.050	.051	.051	.052	.053	.054	.055	.056	.057	.058
6	.059	.060	.061	.062	.063	.064	.065	.066	.067	.068
7	.069	.070	.071	.071	.072	.073	.074	.075	.076	.077
8	.078	.080	.080	.081	.082	.083	.084	.085	.086	.087
9	.088	.089	.090	.091	.092	.093	.094	.095	.096	.097
10	.098	.099	.100	.101	.102	.103	.104	.105	.106	.107
11	.108	.109	.110	.111	.112	.112	.113	.114	.115	.116
12	.117	.118	.119	.120	.121	.122	.123	.124	.125	.126
13	.127	.128	.129	.130	.131	.132	.133	.134	.135	.136
14	.137	.138	.139	.140	.141	.142	.143	.144	.145	.146
15	.147	.148	.149	.150	.151	.152	.153	.154	.155	.156
16	.157	.158	.159	.160	.161	.162	.163	.164	.165	.166
17	.167	.168	.169	.170	.170	.171	.172	.173	.174	.175
18	.176	.177	.178	.179	.180	.181	.182	.183	.184	.185
19	.186	.187	.188	.189	.190	.191	.192	.193	.194	.195
20	.196	.197	.198	.199	.200	.201	.202	.203	.204	.205
21	.206	.207	.208	.209	.210	.211	.212	.213	.214	.215
22	.216	.217	.218	.219	.220	.221	.222	.223	.224	.225
23	.226	.227	.228	.229	.230	.230	.231	.232	.233	.234
24	.235	.236	.237	.238	.239	.240	.241	.242	.243	.244
25	.245	.246	.247	.248	.249	.250	.251	.252	.253	.254
26	.255	.256	.257	.258	.259	.260	.261	.262	.263	.264
27	.265	.266	.267	.268	.269	.270	.271	.272	.273	.273
28	.274	.275	.276	.277	.278	.279	.280	.281	.282	.283
29	.284	.285	.286	.287	.288	.289	.290	.291	.292	.293

Ferric Oxide, Fe_2O_3, Molec. Weight 160. Log. 2.204120.

	0	1	2	3	4	5	6	7	8	9
0	.000	.000	.001	.002	.002	.003	.003	.004	.005	.005
1	.006	.007	.007	.008	.009	.009	.010	.010	.011	.012
2	.013	.013	.014	.014	.015	.015	.016	.017	.017	.018
3	.019	.020	.020	.020	.021	.022	.022	.023	.024	.024
4	.025	.025	.026	.027	.027	.028	.029	.029	.030	.030
5	.031	.032	.032	.033	.034	.034	.035	.035	.036	.037
6	.037	.038	.039	.039	.040	.040	.041	.042	.042	.043
7	.044	.044	.045	.045	.046	.047	.048	.049	.049	.050
8	.050	.050	.051	.052	.052	.053	.054	.054	.055	.055
9	.056	.057	.057	.058	.059	.059	.060	.060	.061	.062
10	.062	.063	.064	.064	.065	.065	.066	.067	.067	.068
11	.069	.069	.070	.070	.071	.072	.072	.073	.074	.074
12	.075	.075	.076	.077	.077	.078	.079	.079	.080	.080
13	.081	.082	.082	.083	.084	.084	.085	.085	.086	.087
14	.087	.088	.089	.089	.090	.090	.091	.092	.092	.093
15	.094	.094	.095	.095	.096	.097	.097	.098	.099	.099

Ferrous Oxide, FeO, Molec. Weight 72. Log. 1.857333.

	0	1	2	3	4	5	6	7	8	9
0	.000	.001	.003	.004	.005	.007	.008	.010	.011	.012
1	.014	.015	.017	.018	.019	.021	.022	.024	.025	.027
2	.028	.030	.030	.032	.033	.035	.036	.038	.039	.040
3	.042	.043	.044	.046	.048	.049	.050	.051	.053	.054
4	.056	.057	.058	.060	.061	.062	.064	.065	.067	.068
5	.070	.071	.072	.074	.075	.076	.078	.079	.080	.082
6	.083	.085	.086	.088	.089	.090	.092	.093	.094	.096
7	.097	.099	.100	.101	.103	.104	.106	.107	.108	.110
8	.111	.112	.114	.115	.117	.118	.120	.121	.122	.124
9	.125	.126	.128	.129	.131	.133	.134	.136	.137	.138
10	.140	.140	.141	.143	.144	.146	.147	.149	.150	.151
11	.153	.154	.156	.157	.158	.160	.161	.162	.164	.165
12	.167	.168	.170	.171	.172	.174	.175	.176	.178	.179
13	.180	.182	.183	.185	.186	.188	.189	.190	.192	.193
14	.194	.196	.197	.199	.200	.201	.203	.204	.206	.207
15	.208	.210	.211	.212	.214	.215	.217	.218	.220	.221

Magnesia, MgO, Molec. Weight 40. Log. 1.602060.

	0	1	2	3	4	5	6	7	8	9
0	.000	.002	.005	.007	.010	.012	.015	.017	.020	.022
1	.025	.027	.030	.032	.035	.037	.040	.042	.045	.047
2	.050	.052	.055	.057	.060	.062	.065	.067	.070	.072
3	.075	.077	.080	.082	.085	.087	.090	.092	.095	.097
4	.100	.102	.105	.107	.110	.112	.115	.117	.120	.122
5	.125	.127	.130	.132	.135	.137	.140	.142	.145	.147
6	.150	.152	.155	.157	.160	.162	.165	.167	.170	.172
7	.175	.177	.180	.182	.185	.187	.190	.192	.195	.197
8	.200	.202	.205	.207	.210	.212	.215	.217	.220	.222
9	.225	.227	.230	.232	.235	.237	.240	.242	.245	.247
10	.250	.252	.255	.257	.260	.262	.265	.267	.270	.272
11	.275	.277	.280	.282	.285	.287	.290	.292	.295	.297
12	.300	.302	.305	.307	.310	.312	.315	.317	.320	.322
13	.325	.327	.330	.332	.335	.337	.340	.342	.345	.347
14	.350	.352	.355	.357	.360	.362	.365	.367	.370	.372
15	.375	.377	.380	.382	.385	.387	.390	.392	.395	.397
16	.400	.402	.405	.407	.410	.412	.415	.417	.420	.422
17	.425	.427	.430	.432	.435	.437	.440	.442	.445	.447
18	.450	.452	.455	.457	.460	.462	.465	.467	.470	.472
19	.475	.477	.480	.482	.485	.487	.490	.492	.495	.497
20	.500	.502	.505	.507	.510	.512	.515	.517	.520	.522
21	.525	.527	.530	.532	.535	.537	.540	.542	.545	.547
22	.550	.552	.555	.557	.560	.562	.565	.567	.570	.572
23	.575	.577	.580	.582	.585	.587	.590	.592	.595	.597
24	.600	.602	.605	.607	.610	.612	.615	.617	.620	.622
25	.625	.627	.630	.632	.635	.637	.640	.642	.645	.647

Lime, CaO, Molec. Weight 56. Log. 1.748188.

	0	1	2	3	4	5	6	7	8	9
0	.000	.002	.003	.005	.007	.009	.010	.012	.014	.016
1	.018	.020	.021	.023	.025	.027	.029	.030	.032	.034
2	.036	.038	.039	.041	.043	.045	.047	.048	.050	.051
3	.053	.055	.057	.059	.060	.062	.064	.066	.068	.070
4	.071	.073	.075	.077	.078	.080	.082	.084	.086	.087
5	.089	.091	.093	.094	.096	.098	.100	.102	.103	.105
6	.107	.109	.110	.112	.114	.116	.118	.120	.121	.123
7	.125	.127	.128	.130	.132	.134	.135	.137	.139	.141
8	.143	.144	.146	.148	.150	.151	.153	.155	.157	.159
9	.160	.161	.164	.166	.168	.169	.171	.173	.175	.177
10	.178	.180	.182	.184	.185	.187	.189	.191	.193	.194
11	.196	.198	.200	.201	.203	.205	.207	.209	.210	.212
12	.214	.216	.218	.219	.221	.223	.225	.226	.228	.230
13	.232	.234	.235	.237	.239	.241	.243	.244	.246	.248
14	.250	.251	.253	.255	.257	.259	.260	.262	.264	.266

Soda, Na_2O, Molec. Weight 62. Log. 1.792392.

	0	1	2	3	4	5	6	7	8	9
0	.000	.001	.003	.005	.006	.008	.009	.011	.013	.014
1	.016	.018	.019	.021	.022	.024	.026	.027	.029	.030
2	.032	.034	.035	.037	.039	.040	.042	.043	.045	.047
3	.048	.050	.051	.053	.055	.056	.058	.059	.061	.063
4	.064	.066	.068	.069	.071	.072	.074	.076	.077	.079
5	.080	.082	.084	.085	.087	.089	.090	.092	.093	.095
6	.097	.098	.100	.101	.103	.105	.106	.108	.109	.111
7	.113	.114	.116	.118	.119	.121	.122	.124	.126	.127
8	.129	.130	.132	.134	.135	.137	.139	.140	.142	.143
9	.145	.147	.148	.150	.151	.153	.155	.156	.158	.159
10	.161	.163	.164	.166	.168	.169	.171	.172	.174	.176
11	.177	.179	.180	.182	.184	.185	.187	.189	.190	.192
12	.193	.195	.197	.198	.200	.201	.203	.205	.206	.208
13	.209	.211	.212	.214	.215	.217	.219	.221	.222	.224
14	.226	.227	.229	.230	.232	.234	.235	.237	.239	.240
15	.242	.243	.245	.247	.248	.250	.251	.253	.255	.256

Potash, K_2O, Molec. Weight 94. Log. 1.973128.

	0	1	2	3	4	5	6	7	8	9
0	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
1	.010	.012	.013	.014	.015	.016	.017	.018	.019	.020
2	.021	.022	.023	.024	.024	.026	.027	.029	.030	.031
3	.032	.033	.034	.035	.036	.037	.038	.039	.040	.041
4	.042	.043	.045	.046	.047	.048	.049	.050	.051	.053
5	.054	.055	.056	.057	.058	.059	.060	.061	.062	.063
6	.064	.065	.066	.067	.068	.069	.070	.071	.072	.073
7	.074	.075	.076	.078	.079	.080	.081	.082	.083	.084
8	.085	.086	.087	.088	.089	.090	.091	.092	.093	.094
9	.096	.097	.098	.099	.100	.101	.102	.103	.104	.105
10	.106	.107	.108	.109	.110	.112	.113	.114	.115	.116
11	.117	.118	.119	.120	.121	.122	.123	.124	.125	.126
12	.127	.129	.130	.131	.132	.133	.134	.135	.136	.137
13	.138	.139	.140	.141	.142	.143	.144	.145	.147	.148
14	.149	.150	.151	.152	.153	.154	.155	.156	.157	.158
15	.159	.160	.162	.163	.164	.165	.166	.167	.168	.169

Water, H_2O, Molec. Weight 18. Log. 1.255273.

	0	1	2	3	4	5	6	7	8	9
0	.000	.005	.011	.016	.022	.028	.033	.040	.044	.050
1	.055	.061	.066	.072	.080	.083	.090	.094	.100	.105
2	.111	.116	.122	.128	.133	.139	.144	.150	.155	.161
3	.166	.172	.178	.183	.189	.194	.200	.205	.211	.216
4	.222	.228	.233	.239	.244	.250	.255	.261	.267	.272
5	.278	.283	.289	.294	.300	.305	.311	.316	.322	.328
6	.333	.339	.344	.350	.355	.361	.367	.372	.378	.383
7	.389	.394	.400	.405	.411	.417	.422	.428	.433	.439
8	.444	.450	.455	.461	.467	.472	.478	.483	.489	.494
9	.500	.505	.511	.517	.522	.528	.533	.539	.544	.550

Carbonic Acid, CO_2, Molec. Weight 44. Log. 1.643453.

	0	1	2	3	4	5	6	7	8	9
0	.000	.002	.004	.007	.009	.011	.014	.016	.018	.020
1	.023	.025	.027	.029	.032	.034	.036	.039	.041	.043
2	.045	.048	.050	.052	.055	.057	.059	.061	.064	.066
3	.068	.070	.073	.075	.077	.080	.082	.084	.086	.089
4	.091	.093	.095	.098	.100	.102	.104	.107	.109	.111
5	.113	.116	.118	.120	.123	.125	.127	.129	.132	.134
6	.136	.139	.141	.143	.145	.148	.150	.152	.154	.157
7	.159	.161	.163	.166	.168	.170	.173	.175	.177	.179
8	.182	.184	.186	.189	.191	.193	.195	.198	.200	.202
9	.204	.207	.209	.211	.2	.216	.218	.220	.223	.225

Titanic Acid, TiO_2, Molec. Weight 82. Log. 1.913814.

	0	1	2	3	4	5	6	7	8	9
0	.000	.001	.002	.003	.005	.006	.007	.008	.010	.011
1	.012	.013	.014	.015	.017	.018	.019	.020	.022	.023
2	.024	.025	.026	.028	.029	.030	.031	.033	.034	.035
3	.036	.038	.039	.040	.041	.043	.044	.045	.046	.047
4	.049	.050	.051	.052	.053	.055	.056	.057	.058	.059
5	.061	.062	.063	.064	.066	.067	.068	.069	.070	.072
6	.073	.074	.075	.077	.078	.079	.080	.081	.083	.084
7	.085	.086	.088	.089	.090	.091	.092	.094	.095	.096
8	.097	.098	.100	.101	.102	.103	.105	.106	.107	.108
9	.109	.111	.112	.113	.114	.116	.117	.118	.119	.120

Zirconia, ZrO_2, Molec. Weight 122. Log. 2.086360.

	0	1	2	3	4	5	6	7	8	9
0	.000	.001	.001	.002	.003	.004	.005	.006	.006	.007

Phosphoric pentoxide, P_2O_5, Molec. Weight 142. Log. 2.152288.

	0	1	2	3	4	5	6	7	8	9
0	.000	.000	.001	.002	.003	.003	.004	.005	.005	.006
1	.007	.008	.008	.009	.010	.010	.011	.012	.013	.013
2	.014	.015	.015	.016	.017	.017	.018	.019	.020	.020

Sulphuric anhydride, SO_3, Molec. Weight 80. Log. 1.903090.

	0	1	2	3	4	5	6	7	8	9
0	.000	.001	.002	.004	.005	.006	.007	.009	.010	.011
1	.012	.014	.015	.016	.017	.019	.020	.021	.022	.024

Chlorine, Cl, Atomic Weight 35.5. Log. 1.550228.

	0	1	2	3	4	5	6	7	8	9
0	.000	.002	.006	.008	.011	.014	.017	.020	.022	.025

Fluorine, F, Atomic Weight 19. Log. 1.278754.

	0	1	2	3	4	5	6	7	8	9
0	.000	.005	.010	.016	.021	.026	.031	.037	.042	.047

Sulphur, S, Atomic Weight 32. Log. 1.505150.

	0	1	2	3	4	5	6	7	8	9
0	.000	.003	.006	.009	.012	.016	.019	.022	.025	.028
1	.031	.034	.037	.040	.044	.047	.050	.053	.056	.059
2	.062	.066	.069	.072	.075	.078	.081	.084	.087	.091

Chromic oxide, Cr_2O_3, Molec. Weight 152.8. Log. 2.184123.

	0	1	2	3	4	5	6	7	8	9
0	.000	.000	.001	.002	.002	.003	.004	.004	.005	.006
1	.006	.007	.008	.008	.009	.010	.010	.011	.012	.012
2	.013	.014	.014	.015	.016	.016	.017	.018	.018	.019
3	.020	.020	.021	.022	.022	.023	.024	.024	.025	.026
4	.026	.027	.028	.028	.029	.030	.030	.031	.032	.032
5	.033	.034	.034	.035	.036	.036	.037	.038	.038	.039

Nickel oxide, NiO, Molec. Weight 75. Log. 1.875061.
Cobalt oxide, CoO, Molec. Weight 75. Log. 1.875061.

	0	1	2	3	4	5	6	7	8	9
0	.000	.001	.002	.004	.005	.006	.008	.010	.011	.012
1	.013	.015	.016	.017	.019	.020	.021	.023	.024	.025
2	.027	.028	.030	.031	.032	.033	.035	.036	.037	.039

Cupric oxide, CuO, Molec. Weight 79.1. Log. 1.898176.

	0	1	2	3	4	5	6	7	8	9
0	.000	.001	.002	.004	.005	.006	.007	.009	.010	.011

Manganous oxide, MnO, Molec. Weight 71. Log. 1.851258.

	0	1	2	3	4	5	6	7	8	9
0	.000	.001	.003	.004	.005	.007	.008	.010	.011	.012
1	.014	.015	.017	.018	.020	.021	.022	.024	.025	.027
2	.028	.030	.031	.032	.034	.035	.036	.038	.039	.041
3	.042	.043	.045	.046	.048	.049	.050	.052	.053	.055
4	.056	.058	.059	.060	.062	.063	.065	.066	.068	.069
5	.070	.072	.073	.074	.076	.077	.079	.080	.081	.083

Baryta, BaO, Molec. Weight 152.8. Log. 2.184123.

	0	1	2	3	4	5	6	7	8	9
0	.000	.000	.001	.002	.002	.003	.004	.004	.005	.006
1	.006	.007	.008	.008	.009	.010	.010	.011	.012	.012

Strontia, SrO, Molec. Weight 103.5. Log. 2.014940.

	0	1	2	3	4	5	6	7	8	9
0	.000	.000	.002	.003	.004	.005	.006	.007	.008	.009
1	.010	.011	.011	.012	.013	.014	.015	.016	.017	.018

Lithia, Li_2O, Molec. Weight 30. Log. 1.477121.

	0	1	2	3	4	5	6	7	8	9
0	.000	.003	.006	.010	.013	.016	.020	.023	.026	.030
1	.033	.036	.040	.043	.046	.050	.053	.056	.060	.063

FACTORS FOR TURNING MOLECULAR PROPORTIONS INTO PERCENTAGES.

In each case multiply the molecular proportion of the given constituent oxide or oxides by factor cited below, which is usually the molecular weight of the compound. (For explanation see p. 169.)

Mineral.	Composition.	Oxide Used.	Factor.
Quartz,	SiO_2	SiO_2	60
Orthoclase,	$K_2O,Al_2O_3,6SiO_2$	K_2O	556
Albite,	$Na_2O,Al_2O_3,6SiO_2$	Na_2O	524
Anorthite,	$CaO,Al_2O_3,2SiO_2$	CaO	278
Nephelite,	$Na_2O,Al_2O_3,2SiO_2$	Na_2O	284
Leucite,	$K_2O,Al_2O_3,4SiO_2$	K_2O	436
Melilite,	$12CaO,2Al_2O_3,9SiO_2$	CaO	118
Analcite,	$Na_2O,Al_2O_3,4SiO_2 2H_2O$	Na_2O	440
Sodalite,	$3(Na_2O,Al_2O_3,2SiO_2) + 2NaCl$	Na_2O	323
Hauynite,	$3(Na_2O,Al_2O_3,2SiO_2) + 2CaSO_4$	Na_2O	375
Noselite,	$3(Na_2O,Al_2O_3,2SiO_2) + 2Na_2SO_4$	Na_2O	379
Muscovite,	$K_2O,Al_2O_3,2SiO_2$	K_2O	316
	$H_2O,Al_2O_3,2SiO_2$	H_2O	240
Biotite,	$2(K_2O,Al_2O_3,2SiO_2)$	K_2O	316
	$2(K_2O,Fe_2O_3,2SiO_2)$	K_2O	374
	$2(H_2O,Al_2O_3,2SiO_2)$	H_2O	240
	$2(H_2O,Fe_2O_3,2SiO_2)$	H_2O	298
	$2MgO,SiO_2$	SiO_2	140
	$2FeO,SiO_2$	SiO_2	204
Amphiboles and Pyroxenes,	MgO,SiO_2	MgO	100
	FeO,SiO_2	FeO	132
	CaO,SiO_2	CaO	116
	MnO,SiO_2	MnO	131
	MgO,Al_2O_3,SiO_2	MgO	202
	MgO,Fe_2O_3,SiO_2	MgO	260
	FeO,Al_2O_3,SiO_2	FeO	234
	$Na_2O,Fe_2O_3,4SiO_4$	Na_2O	462
Olivine,	$2MgO,SiO_2$	SiO_2	140
	$2FeO,SiO_2$	SiO_2	204
Magnetite,	FeO,Fe_2O_3	Fe_2O_3	232
Ilmenite,	FeO,TiO_2	TiO_2	154
Apatite,	$9CaO,3P_2O_5,CaCl_2$	CaO	116
	$9CaO,3P_2O_5,CaF_2$	CaO	112
Kaolin,	$Al_2O_3,2SiO_2,2H_2O,$	Al_2O_3	258
Serpentine,	$3MgO,2SiO_2,2H_2O$	MgO	92
Calcite,	CaO,CO_2	CaO	100
Magnesite,	MgO,CO_2	MgO	84

Mineral.	Composition.	Oxide Used.	Factor.
Titanite,	CaO,TiO_2,SiO	TiO_2	198
Garnet,			
Grossularite,	$3CaO,Al_2O_3,3SiO_2$	Al_2O_3	450
Almandite,	$3FeO,Al_2O_3,3SiO_2$	Al_2O_3	498
Andradite,	$3CaO,Al_2O_3,3SiO_2$	Fe_2O_3	508
Chromite,	FeO,Cr_2O_3	Cr_2O_3	224.8
Chlorite,	$2H_2O,2MgO,Al_2O_3,SiO_2$	H_2O	139
	$2H_2O,2MgO,Fe_2O_3,SiO_2$	H_2O	148

GLOSSARY.

NOTE. — In the following definitions, when fuller explanations are to be found in preceding pages, references are given to them and they should be consulted. No attempt has been made to unnecessarily repeat previous statements.

A

Aa, a Hawaian word specially introduced into American usage by Maj. C. E. Dutton, and employed to describe jagged, scoriaceous, lava flows. It is contrasted with pahoehoe. 4th Ann. Rep. U. S. Geol. Survey, 95.

Ablation, a name applied to the process whereby residual deposits are formed by the washing away of loose or soluble materials.

Absarokite, a general name given by Iddings to a group of igneous rocks in the Absaroka range, in the eastern portion of the Yellowstone Park. They have porphyritic texture with phenocrysts of olivine and augite in a groundmass, either glassy or containing leucite, orthoclase or plagioclase, one or several. They range chemically, SiO_2, 46–52; Al_2O_3, 9–12; MgO, 8–13; alkalies, 5–6.3, with potash in excess. The name is of greatest significance when taken in connection with shoshonite and banakite. Jour. of Geol., III., 936.

Abyssal-rocks, a synonym of plutonic rocks as used in preceding pages. The word has been suggested and especially used by W. C. Brögger.

Accessory components or minerals in rocks are those of minor importance or of rare occurrence, whose presence is not called for by the definition of the species.

Acidic, a descriptive term applied to those igneous rocks that contain more than 65 per cent. SiO_2, as contrasted with the medium of 65 per cent. to 55 per cent. and the basic at less that 55 per cent.; still the limits are somewhat elastic.

Acmite-trachyte, a trachyte whose pyroxene is acmite or ægirite and whose feldspar is anorthoclase. It therefore differs from normal trachyte in its prevailing soda instead of potash, as is shown by the acmite, a soda-pyroxene, and the anorthoclase, a soda-feldspar. The acmite-trachytes are intermediate between the true trachytes and the

phonolites. They were first described from the Azores (Mügge, Neues Jahrbuch, 1883, II., 189) and have also been found in the Crazy Mountains, Mont.; see p. 40, Anals. 4 and 5.

Adamellite, a name proposed by Cathrein as a substitute for tonalite, on the ground that tonalite means a hornblende-biotite granite, rich in plagioclase, whereas adamellite, which better describes the rocks at the Tyrolese locality, means a quartz-hornblende-mica-diorite with granitic affinities. Adamellite emphasizes the dioritic characters; tonalite, the granitic. The name is derived from Monte Adamello, near Meran, Tyrol, the locality of tonalite. Neues Jahrb., 1890, I., 75. Brögger uses it for acidic quartz-monzonite. Eruptions-folge bei Predazzo, 61.

Adinole, a name for dense felsitic rocks, composed chiefly of an aggregate of excessively fine quartz and albite crystals, such that on analysis the percentage of soda may reach 10. Actinolite and other minerals are subordinate. Adinoles occur as contact rocks, associated with diabase intrusions and are produced by them from schists (compare spilosite and desmite). They also constitute individual beds in metamorphic series. (Compare porphyroid, hälleflinta.) The name was first given by Beudant, but has been especially revived by Lossen. Zeits. d. d. Geol. Ges., XIX., 572, 1867.

Adobe, a word widely employed in Spanish America and neighboring regions for the argillaceous, residual soils or other clayey deposits of the arid countries, from which the sun-baked bricks are made.

Ægirite, the name of this soda pyroxene is often prefixed to normal rock-names because of its presence, as for instance, ægirite-granite, ægirite-trachyte. Microscopic study has shown that the mineral is much more widely distributed than was formerly appreciated.

Aerolite, a synonym of meteorite.

Agglomerate, a special name for volcanic breccias as distinguished from other breccias and from conglomerates.

Ailsyte, a name derived from Ailsa Craig, Scotland, and suggested for a micro-granite with considerable riebeckite, which occurs there. M. F. Heddle, Trans. Edinburgh Geol. Soc., VII., 265, 1897.

Akerite, a special name coined by Brögger for a variety of syenite at Aker, Norway, that is a granitoid rock consisting of orthoclase, considerable plagioclase, biotite, augite and some quartz. (W. C. Brögger, Zeitsch. f. Krys., 1890, 43.)

Alaskite, a name proposed by J. E. Spurr as a general term for all rocks consisting essentially of quartz and alkali feldspar, without regard to texture. Those with xenomorphic or hypautomorphic textures are alaskites proper; those with panautomorphic textures alaskite-aplite;

those with porphyritic texture involving a fine-grained or aphanitic groundmass, tordrillites (which see). Amer. Geol., XXV., 231, 20th Ann. Rep. U. S. G. S. Part 7, 189, 195.

Albite, the name of the mineral is sometimes prefixed to normal rock names, because of its presence in the rocks: as for instance albite-diorite, albite-porphyrite.

Albitite, a name applied by H. W. Turner to granitoid rocks, consisting essentially of albite. The original occurrence is a series of dikes cutting serpentine, near Meadow valley, Plumas Co., Calif., but under the name soda-syenite, similar rocks have been described from various places on the Pacific coast. (Amer. Geologist, June, 1896, 378–380.)

Albitophyre, a name given by A. Michel-Levy to a dike rock, in which are developed very large, polysynthetic phenocrysts of albite. In the groundmass are microlites of the same mineral, together with chlorite and limonite. Comptes rendus, CXXII., 265, 1896.

Alboranite, a variety of hypersthene-andesite, poor in soda, from the island of Alboran, east of the Straits of Gibralter, and 80 km. south from Spain. The recasting of a typical analysis gave plagioclase, (Ab_1 $An_{4.5}$), 41.5; hypersthene, 5; augite, 20; magnetite, 9; basis, 24.5; total, 100. The rocks are porphyritic with plagioclase phenocrysts. F. Becke, Tschermaks Mittheilungen, XVIII., 553, 1899.

Aleutite, a name proposed by J. E. Spurr for those members of his belugites (which see) having a porphyritic texture with an aphanitic or finely crystalline groundmass. Amer. Geol., XXV., 233, 1900. 20th Ann. Rep. U. S. G. S., Part 7, 209.

Algovite, a name proposed by Winkler, for a group of rocks, practically diabases, or porphyritic phases of the same, in the Algäuer Alps. They also embrace gabbros according to Roth, and are doubtless various textural varieties of an augite-plagioclase magma. Neues Jahrbuch, 1895, 641.

Allalinite, a name derived from Allalin mountain in the Pennine Alps, and applied by H. Rosenbusch to an actinolite-saussurite rock, which had been derived from gabbro without losing the characteristic texture of the latter. That is, the allalinites are not sheared and crushed as in the flaser-gabbros and forellensteins. Massige Gest., 328, 1895.

Allivalite, Harker's name for the granitoid, anorthite-olivine rocks with the two minerals in equal amounts or with the feldspar in excess—small proportions of other minerals such as augite may be present. "Geology of the Small Isles." Mem. British Geol. Survey, 69–77, 1908.

Allochetite, a name derived from the Allochet valley on the eastern side of the Monzoni region of the Austrian Tyrol and applied by J. A.

Ippen to a dike rock related to the tinguaites. The allochetite is porphyritic in texture and contains phenocrysts of plagioclase (labradorite), orthoclase, titanaugite, nephelite and magnetite, in a groundmass of augite, magnetite, hornblende, nephelite, orthoclase and occasional biotite. (Verh. der. k. k. geol. Reichsanstalt, Vienna, 1903, 132.)

Allogenic, originating elsewhere; whether applied to the components of a clastic rock or to xenoliths. The contrasted term is authigenic.

Allotriomorphic, an adjective coined by Rosenbusch in 1887 to describe those minerals in an igneous rock which do not possess their own crystal faces or boundaries, but which have their outlines impressed upon them by their neighbors. They result when a number of minerals crystallize at once so as to interfere with one another. They are especially characteristic of granitoid textures. The word was unnecessary, as xenomorphic had been earlier suggested for the same thing, but it is in more general use than xenomorphic. See also anhedron.

Alluvium, Lyell's name for the deposit of loose gravel, sand and mud that usually intervenes in every district between the superficial covering of vegetable mould and the subjacent rock. The name is derived from the Latin word for an inundation (Elements of Geol., 6th Ed., N. Y., 1859, p. 79). It was employed by Naumann as a general term for sediments in water as contrasted with eolian rocks. It is generally used to-day for "the earthy deposit made by running streams or lakes, especially during times of flood. (Dana's Manual, 1895, p. 81.) In a stratigraphical sense it was formerly employed for the more recent water-sorted sediments, as contrasted with "diluvium," or the stratified and unstratified deposits from the melting of the continental glacier of the Glacial Period. This use, with fuller study of the Glacial deposits, is practically obsolete.

Alnoite, a very rare rock with the composition of a melilite basalt, that was first discovered in dikes on the island of Alnö, off the coast of eastern Sweden. The special name was given it by Rosenbusch to emphasize its occurrence in dikes and its association as a very basic rock, with nepheline syenite. A'noite has been discovered near Montreal by F. D. Adams (Amer. Jour. Sci., April, 1892, p. 269) and at Manheim Bridge, N. Y., by C. H. Smyth, Jr. (Amer. Jour. Sci., Aug., 1893, 104).

Alsbachite, a name given by Chelius to a variety of granite-porphyry, forming dykes in Mt. Melibocus, and containing large mica crystals and rose-red garnets. Notizbl. Ver. Erdk. zu Darmstadt, 1892, Heft 13, 1.

Alum-shales, shales charged with alum, which in favorable localities may be commercially leached out and crystallized. The alum results

from the decomposition of pyrites, because the sulphuric acid, thus produced, reacts on the alumina present, yielding the double sulphate that is alum.

Ampelite, a name, specially current among the French, for shales, charged with pyrite and carbonaceous matter, which may yield alum-shales.

Amphibole, the generic name for the group of bisilicate minerals whose chief rock-making member is hornblende. It is often prefixed to those rocks which have hornblende as a prominent constituent, as amphibole-andesite, amphibole-gabbro, amphibole-granite, etc.

Amphibolite, a metamorphic rock consisting chiefly of hornblende, or of some member of the amphibole group. It is as a rule a synonym of hornblende-schists, but is preferable to the latter, when the schistosity is not marked. See p. 140.

Amygdaloids are cellular lavas, whose cavities, caused by expanding steam-bubbles, resemble an almond in size and shape. Basaltic rocks are most prone to develop them. The term is used in the form of the adjective, amygdaloidal, and properly should be limited to this. As a noun it is also employed for secondary fillings of the cavities, which are usually calcite, quartz or some member of the zeolite group. Amygdaloidal rocks are of chief interest in America, because certain basaltic lava sheets on Keweenaw Point, Lake Superior, have their amygdules filled with native copper and are important sources of the metal. Amygdaloidal cavities are limited to the upper and lower portions of lava sheets. The name is derived from the Greek word for almond.

Analcite-basalt, a variety of basalt whose feldspar is more or less replaced by analcite. The analcite is at times in such relations as to give reason for thinking it an original mineral and not an alteration product from feldspar. Analcite-basalts occur in the Highwood Mountains, Mont. (See W. Lindgren, 10th Census, XV., 727, Proc. Calif. Acad. Sci., Ser. II., Vol. III., p. 51 Comptes Rendus, Fifth Internat. Geol. Cong., 364.) Analcite-diabase has been met in California. (H. W. Fairbanks, Bull. Dept. Geol. Univ. of Calif., I., 173.) See also in this connection teschenite.

Analcite-tinguaite, tinguaite (which see) with considerable analcite,

Analcitite, Pirsson's name for the olivine-free analcite-basalts. Jour. Geol., IV., 690, 1896.

Anamesite, an old name suggested by von Leonhard, in 1832, for those finely crystalline basalts, which texturally stand between the dense typical basalt, and the coarser dolerites. The name is from the Greek for "in the middle."

Anamorphic, a term coined by C. R. Van Hise in discussing the processes of metamorphism, for the deep-seated reactions whereby minerals are built up, in the so-called zone of cementation. The components, descending in solution, are precipitated as anamorphic minerals in the cavities of buried rocks, or else older components are reorganized into new minerals. The antithesis is katamorphic, which refers to the breaking down of compounds in the upper zone or zone of weathering, or oxidation. The katamorphic reactions largely provide the materials for anamorphic reconstruction.

Anatexis, a name suggested by J. J. Sederholm for the process of the recomposition into a new and fresh igneous rock, of the weathered and disintegrated components of an older one, when they are deeply buried in the earth. (Bull. Com. Geol. de Finlande, 23, 1907.)

Andalusite-hornstone, a compact contact rock containing andalusite. It is usually produced from shales or slates by intrusions of granite.

Andendiorite, a tertiary, quartz-augite-diorite, which occurs in areas like islands in the midst of the volcanic rocks of the Chilean Andes. The quartzes are remarkable for their inclusions of glass and of fluid with salt crystals. A. W. Stelzner, Beiträge Geol. d. Argent. Republik, 212, 1885.

Andengranite, a biotite bearing hornblende-granite, similar in occurrence and microscopic features to the andendiorite, l. c., 208.

Andesite, volcanic rocks of porphyritic or felsitic texture, whose crystallized minerals are plagioclase and one or more of the following: biotite, hornblende and augite. The name was suggested by L. von Buch in 1836, for certain rocks from the Andes, resembling trachytes, but whose feldspar was at first thought to be albite, and later oligoclase. See p. 62.

Anhedron, a name proposed by L. V. Pirsson for the individual, mineral components of igneous rock, that lack crystal boundaries, and that cannot therefore be properly called crystals according to the older and most generally accepted conception of a crystal. Xenomorphic and allotriomorphic are adjectives implying the same conception. The name means without planes. Bulletin Geol. Society of America, Vol. VII., p. 492, 1895.

Anhydrite; the name of the mineral is also used as the name of a rock, when entire beds of it appear in a sedimentary series, most often in association with rock-salt and gypsum. Anhydrite in $CaOSO_3$.

Anogene, a general name for rocks that have come up from below; *i. e.*, eruptive rocks. See p. 15.

Anorthite-rock, a name given by R. D. Irving to a coarsely crystal-

line, granitoid rock, that consists almost entirely of anorthite (Monograph V., U. S. Geol. Survey, p. 59). It was observed on the Minnesota shore of Lake Superior. The rock is a feldspathic extreme of the gabbro group, practically an anorthosite formed of anorthite.

Anorthosite, a name applied by T. Sterry Hunt (Geol. Survey Canada, 1863, 22) to granitoid rocks that consist of little else than labradorite and that are of great extent in eastern Canada and the Adirondacks. The name is derived from anorthose, the French word for plagioclase, and is not to be confounded with anorthite, with which it has no necessary connection, although anorthosite is used as a general name for rocks composed of plagioclase. Mt. Marcy and the neighboring high peaks of the Adirondacks are formed of it. The rocks are extremes of the gabbro group, into whose typical members they shade by insensible gradations. See p. 80.

Apachite, a name suggested by Osann, from the Apache, or Davis Mountains of western Texas, for a variety of phonolite, that varies from typical phonolites in two particulars. It has almost as much of amphiboles and of ænigmatite as of pyroxene, whereas in normal phonolites the former are rare. The feldspars of the groundmass are generally microperthitic. Tscher. Mitth., XV., 454.

Aphanite, an old name, now practically obsolete, for dense, dark rocks, whose components are too small to be distinguished with the eye. It was chiefly applied to finely crystalline diabases. An adjective, aphanitic, is still more or less current.

Aplite is now chiefly applied to the muscovite-granite that occurs in dikes, and that is, as a rule, finely crystalline. Its original application was to granites poor or lacking in mica. See p. 34. The name is from the Greek for simple.

Apo, the Greek preposition for "from," suggested by F. Bascom as a prefix to the names of various volcanic rocks to describe the devitrified or silicified varieties, mostly of ancient date, that result from them, and that indicate their originals only by the preservation of characteristic textures. Thus apobsidian, aporhyolite, apandesite, apobasalt, etc., have been used. See p. 31. Many rocks called by the old indefinite name petrosilex are of this character. Journal of Geology, I., 828, Dec., 1893.

Arenaceous, an adjective applied to rocks that have been derived from sand, or that contain sand.

Arenite, a general name, suggested by A. W. Grabau for fragmental rocks of all sorts, whose grain is that of sand. Prefixes are used to indicate the nature of the sand, as silicarenite, for quartz sands; cal-

carenite for limestone composed of calcite grains, etc. The name is especially significant as applied to limestones. (Bulletin Geol. Soc. Amer. 14: 348–352.)

Argillite, a synonym of slate.

Ariegite, a name given by A. Lacroix to a special family of granitoid rocks, consisting primarily of monoclinic pyroxene and spinel. Subvarieties result from the presence of amphibole and garnet. The rocks are found in the French Pyrenees, in the department of Ariege, from which they take their name. They are most closely related to the pyroxenites. Comptes Rendus, VIII., International Geological Congress, 809, 1901.

Arkite, a name based on the common abbreviation Ark. for Arkansas, and given by H. S. Washington to a rock which occurs near the Diamond Jo quarry, Magnet Cove, Ark. The rock was earlier called leucite-porphyry, by J. F. Williams. Washington defines it as "a holocrystalline porphyritic, leucocratic combination of leucite (or pseudoleucite) and nephelite with pyroxene and garnet." Jour. Geology, IX., 615–617, 1901.

Arkose, a special name for a sandstone rich in feldspar fragments, as distinguished from the more common, richly quartzose varieties. See p. 98.

Aschaffite, a name suggested by Gümbel for a dike rock occurring near Aschaffenburg, Bavaria. (Bavaria, Vol. IV., Heft 11, p. 23.) It is defined by Rosenbusch as a dioritic, dike rock, containing quartz and plagioclase, with biotite as the chief dark silicate.

Aschistic applied to dikes, which represent an original and undifferentiated or undivided magma—whereas, complementary or diaschistic dikes of contrasted acidic and basic composition represent a differentiation or division into two. Aschistic literally means undivided and diaschistic, divided. (Pirsson, Rocks and Rock-Minerals, 169.)

Ashbed diabase, a local name used on Keweenaw Point, Lake Superior, for a rock resembling a conglomerate, but which is interpreted by Wadsworth as a very scoriaceous, amygdaloidal sheet into which much sand was washed in its early history. See Monograph V., U. S. Geol. Surv., p. 138.

Asiderite, Daubrée's name for stony meteorites that lack metallic iron.

Asperite, a collective name suggeted by G. F. Becker for the rough cellular lavas whose chief feldspar is plagioclase, but of which it is impossible to speak more closely without microscopic determination. The name is intended for general field use much as trachyte was em-

ployed in former years. It is coined from the Latin word for rough. Also Monograph XIII., U. S. Geol. Surv., p. 151.

Ataxite. See under Taxite.

Atmogenic, a general name proposed by A. W. Grabau for the rocks which are due to the work of the atmosphere, *i. e.*, the æolian rocks and those due to atmospheric weathering. It forms one in a logical sequence, pyrogenic; hydrogenic; atmogenic.

Augen, the German word for eyes; used as a prefix before various rock names, but more especially gneiss, to describe larger minerals or aggregates of minerals, which are in contrast with the rest of the rock. In the gneisses, feldspars commonly form the augen and are lenticular with the laminations forking around them, in a way strongly suggesting an eye. The term is seldom used in any other connection than with gneiss in America.

Augite, the commonest rock-making pyroxene. As distinguished from other pyroxenes augite refers to the dark varieties with considerable alumina and iron. The name is used as a descriptive prefix to many rocks that contain the mineral, as for instance augite-andesite, augite-diorite, augite-gneiss, augite-granite, augite-syenite, etc.

Augitite, non-feldspathic, porphyritic rocks consisting essentially of a glassy groundmass, with disseminated augite and magnetite. Various minor accessories also occur. The name was first applied by Doelter to lavas from the Cape Verde Islands. (Verhandl. d. k. k. Geol. Reichsanst., 1882, 143.) See above, pp. 73, 74.

Augitophyre, a basalt with phenocrysts of augite.

Aureole, the area that is affected by contact metamorphism around an igneous intrusion. See p. 125.

Authigenous, an adjective coined by Kalkowsky to describe those minerals which form in sediments after their deposition, as for instance during metamorphism. The name emphasizes in its etymology the local origin of the minerals as contrasted with that of the other components, the latter having been brought from a distance.

Autochthonous, an adjective derived from two Greek words, meaning indigenous. It is applied to those rocks that have originated in situ, such as rock salt, stalagmitic limestones, peat, etc., but it is of rare use.

Autoclastic, an adjective applied to fragmental rocks, which owe their fragmental character to crushing or dynamic metamorphism, and not to sedimentation.

Automorphic is the contrasted term with xenomorphic or allotriomorphic, and is used to describe those minerals in rocks, which have

their own crystal boundaries. The later suggested word, idiomorphic, means the same thing and is somewhat more widely used.

Avezacite, a name given by A. Lacroix to a peculiar, cataclastic rock now found in veins or dikes in a peridotite at Avezac-Prat, in the French Pyrenees. The rock is dense, black and brittle, but contains large basaltic hornblendes and yellow sphenes, in a fine-grained mass, which, on microscopic examination is resolved into a cataclastic aggregate of apatite, sphene, titaniferous magnetite, ilmenite, hornblende, augite, and rarely olivine and biotite. It is supposed to have resulted from the crushing of basic pegmatitic veins or dikes. Comptes Rendus, VIII., International Geological Congress, 826–829, 1901.

Axiolite, a term coined by Zirkel in his report on Microscopical Petrography, for the U. S. Geol. Survey along the Fortieth Parallel, 1876, to describe those spherulitic aggregates that are grouped around an axis rather than around a point. The application comes in microscopic work rather than in ordinary determination.

B

Banakite, a general name given by Iddings to a group of igneous rocks in the eastern portion of the Yellowstone Park, and chiefly in dikes. They are porphyritic and richly feldspathic. The phenocrysts are labradorite and the groundmass consists of alkali-feldspars. A little biotite and subordinate augite may be present. Chemically they range SiO_2, 51–61; Al_2O_3, 16.7–19.6; CaO, 3.5–6; MgO, 1–4; Na_2O, 3.8–4.5; K_2O, 4.4–5.7. The group should be considered in connection with absarokite and shoshonite. Jour. of Geol., III., 937.

Banatite, a name coined by B. v. Cotta in 1865 to describe the dioritic rocks that are connected with a series of ore deposits in the Austrian province of the Banat. Accurate microscopical study has shown them to be of such varying mineralogy that the name has now slight definite significance. The rocks are largely quartz-diorites. Erzlagerstätten im Banat und in Serbien, 1865.

Barolite, Wadsworth's name for rocks composed of barite or celestite. Rept. of State Geol. Mich., 1891–92, p. 93

Barysphere, a term for the deep interior portions of the earth, presumably composed of heavy metals or minerals. It is contrasted with lithosphere, the outer stony shell.

Basalt, a word of ancient but uncertain etymology as stated on p. 72. It is employed as a rock name in its restricted sense for porphyritic and felsitic rocks consisting of augite, olivine and plagioclase with varying amounts of a glassy base which may entirely disappear. Its subdivision

into basalt and basalt-porphyry, on the proportions of phenocrysts, is described in the text. In a broader sense the basalt or basaltic group is used to include all the dark, basic volcanic rocks, such as the true basalts; the nepheline-, leucite- and melilite-basalts; the augites and limburgites; the diabases, and melaphyres. The word basalt is an extremely useful field name, as in many instances the finer discriminations can only be made with the microscope.

Basanite, a very old term, first used as a synonym of basalt; also formerly applied to the black, finely crystalline quartzite, used by old-time workers in the precious metals as a touch-stone or test-stone to distinguish gold from brass by the streak. This variety was often called Lydian stone or lydite. Basanite is now universally employed for those volcanic rocks, that possess a porphyritic or felsitic texture and that contain plagioclase, augite, olivine and nepheline or leucite, one or both, each variety being distinguished by the prefix of one or the other, or of both of the last named minerals. See p. 72.

Basanitoid, a term suggested by Bücking for basaltic rocks, without definite nepheline, but with a gelatinizing, glassy base (H. Bücking, Jahrb. d. k. k. preus. Landesanst., 1882).

Base or **Basis** is employed to describe that part of a fused rock magma that in cooling fails to crystallize as recognizable minerals, but chills as a glass or related, amorphous aggregate. It differs thus from groundmass, which is the relatively fine portion of a porphyritic rock as distinguished from the phenocrysts.

Basic, a general descriptive term for those igneous rocks that are comparatively low in silica. 55 or 50 per cent. is the superior limit. See also *Acidic* and *Medium.*

Batholite, a name suggested by Suess for the vast irregular masses of plutonic rocks that have crystallized in depth and that have only been exposed by erosion. See p. 15. The word is also spelled bathylite, and batholith. The last named is now generally preferred.

Bed, the smallest division of a stratified series, and marked by a more or less well-defined divisional plane from its neighbors above and below.

Beerbachite, a name given by Chelius to certain small dikes, associated with and pentrating large, gabbro masses, and having themselves the composition and texture of gabbro. The name was coined in the attempt to carry out the questionable separation of the dike rocks from large, plutonic or volcanic masses of the same mineralogy and often practically the same structures. Notizbl. Ver. Erdkunde, Darmstadt, 1892, Heft 13, p. 1.

Bekinkinite, a name derived from the Bekinka mountain in Madagascar and coined by H. Rosenbusch (Massige Gesteine, 4th ed., p. 441) for a variety of ijolite originally described by A. Lacroix. The rock consists of about 75 per cent. titanaugite, with nephelite, as the other chief constituent. There is some anorthoclase, and accessory olivine, apatite and leucoxene. Bekinkinite is believed to correspond to a deep-seated nephelite-basalt.

Belonite, rod or club-shaped microscopic minerals, which usually occur as embryonic crystals in a glassy rock.

Belugite, a name based upon the Beluga river, Alaska, and suggested by J. E. Spurr for a transition group of plagioclase rocks between his diorites and diabases. Spurr restricts the name diorite to those plagioclase rocks (without regard to the dark silicate) whose plagioclase belongs in the andesine-oligoclase series. The diabase group on the other hand contains those whose plagioclase belongs in the labradorite-anorthite series. Belugites with a porphyritic texture and a fine-grained or aphanitic groundmass are called aleutites. Amer. Geol., XXV., 231, 1900. 20th Ann. Rep. U. S. Geol. Survey, Part 7, 195.

Benches, a name applied to ledges of all kinds of rock that are shaped like steps or terraces. They may be developed either naturally in the ordinary processes of land-degradation, faulting, and the like; or by artificial excavation in mines and quarries.

Beresite, a name coined by Rose many years ago for a muscovite-granite that forms dikes in the gold district of Beresovsk in the Urals. It is, therefore, practically a synonym of aplite, as earlier defined, but some of the beresites have since been shown to be practically without feldspar, and to form a very exceptional aggregate of quartz and muscovite. (Arzruni, Zeitsch. d. d. g., Gesellsch., 1885, 865.) The muscovite may be secondary and really sericite.

Binary-granite, a term used in older geological writings for those varieties of granite that are chiefly quartz and feldspar. See p. 35. It has recently been applied to granites with two micas. C. R. Keyes, 15th Ann. Rep. Dir. U. S. Geol. Survey, 714.

Biotite is used as a prefix to many names of rocks that contain this mica; such as biotite-andesite, biotite-gneiss, biotite-granite, etc.

Bituminous, an adjective applied to rocks with much organic, or at least carbonaceous matter, mostly in the form of the hydrocarbons which are usually described as bitumen.

Blackband, the black, bituminous carbonate of iron, which forms beds in sedimentary series containing coal-seams. Although once an object of mining in Ohio, West Virginia and Pennsylvania, it has practically dropped out of use in the United States.

Blairmorite, an analcite-trachyte named by Cyril Knight after Blairmore, a town in southwestern Alberta, Can., near the Crows Nest Pass coal fields. Although only found as yet in tuffs, the rock is recognizable as a new species. Phenocrysts of orthoclase and analcite (at first considered leucite) are set in a groundmass of predominant orthoclase rods, some plagioclase, analcite and titanite. (Cyril Knight, Canadian Record of Science, IX., 275, 1905.)

Blaviérite, a peculiar contact rock occurring at several places in the ancient massifs of Mayenne and of the Pyrenees, in France, It results from the action of intrusive microgranites, upon sericite schists. While preserving the schistose structure, it has in addition to the fine micaceous components of the schist, dihexahedral quartzes with orthoclase and oligoclase, apparently referable to the intrusive. (L. Bergeron, Bull. Soc. géol. de France, 1888 (3), XVII., 58.)

Blue-ground, local miners' name for the decomposed peridotite or kimberlite that carries the diamonds in the South African mines.

Bojite, a name given by E. Weinschenk to a variety of gabbro, which occurs in association with the graphite of northern Bavaria. It differs from normal gabbro in containing hornblende, in addition to augite, and the name is intended to indicate a group of hornblende gabbros, just as norite implies those with hypersthene. The original bojite contained brown hornblende, colorless pyroxene, and reddish brown biotite. In amount equal to all of these is a plagioclase (labradorite-bytownite), often not multiple-twinned. As accessories there were zircon, apatite, titanite, pyrite and magnetite. Abh. d. k. bay. Akad. d. Wissensch., II Classe, XIX., 33.

Bombs, masses of lava expelled from a volcano by explosions of steam. They fall as rounded masses and lie on the slopes of the cone, or become buried in tuffs.

Boninite, Petersen's name for a glassy phase of andesite with bronzite, augite and a little olivine, from the Bonin Islands, Japan. Jahrb. Hamburg Wissensch. Anst., VIII., 1891. Compare sanukite.

Borolanite, a rare rock related to the nephelite-syenites and described by Horne and Teall from Borolan, Sutherlandshire, Scotland. It has granitoid texture, and consists principally of orthoclase and the variety of garnet called melanite. As accessory minerals, biotite, pyroxene, alteration products of nephelite, sodalite, titanite, apatite and magnetite appear. (Trans. Roy. Soc. of Edinburgh, 1892, p. 163.)

Bostonite, a name proposed by Hunter and Rosenbusch for certain dikes, having practically the mineralogical and chemical composition of trachytes or porphyries, except that anorthoclase (and therefore soda)

is abnormally abundant and dark silicates are few or lacking They are much the same as dike-keratophyres and were named in carrying out the questionable separation of the dike-rocks, as a distinct grand division from the plutonic and volcanic rocks. The name was suggested by their supposed presence near Boston, Mass., but Marblehead, 20 miles or more distant, is their nearest locality. They have been since met in largest amount on the shores of Lake Champlain and in the neighboring parts of Canada. Tscher. Min. u. Petrog. Mitth., 1890, 447. See also Bull. 107, U. S. Geol. Survey.

Bouteillenstein, *i. e.*, bottlestone, a peculiar green and very pure glass, found as rolled pebbles near Moldau, Bohemia. It is also called moldauite and pseudochrysolite, the latter from its resemblance to olivine. It is not certainly a terrestrial rock. In later years many have believed the pebbles to be small meteorites of unusual composition.

Boulder-clay, unsorted glacial deposits, consisting of boulders and clay; till; hardpan.

Breccia, a fragmental rock whose components are angular and therefore, as distinguished from conglomerates, are not water-worn. There are friction or fault breccias, talus-breccias and eruptive breccias. The word is of Italian origin. See p. 93.

Broccatello, an Italian word for a brecciated and variegated marble.

Bronzite is often used as a prefix to the names of rocks containing the mineral. Rocks of the gabbro family are the commonest ones that have the prefix.

Brotocrystals, etc. A. C. Lane has suggested the following five varieties of phenocrysts: (1) **Brotocrystals,** those phenocrysts whose corroded or embayed outlines prove that they were formed at a period antedating the eruptive stage. The name is from the Greek and means "eaten" or "gnawed" crystal. (2) **Rhyocrystal,** those phenocrysts which have sharp, crystallographic outlines, and which are arranged in flow-lines, so that they are clearly products of the effusive period. The name, suggested by F. E. Wright, means a "flow-crystal." (3) **Eocrystals,** those phenocrysts which are developed under the conditions prevailing in the magma after it has come to rest. They increase uniformly in size from border of the igneous mass or most rapidly chilled portion, to the center or most slowly cooled portion. The name means "early crystal." (4) **Oriocrystals,** those phenocrysts whose conditions of formation lie midway between the great heat of the original intrusive and the relative coldness of the walls. As the former cools and the latter heats up, conditions are established at the border which very

slowly change and which permit the growth of large individuals. The word means "border crystal." (5) **Metacrystals,** relatively large crystals in metamorphosed sedimentary and igneous rocks, such as staurolite, garnet, andalusite, etc. The word means metamorphic crystal. (Bull. Geol. Soc. Amer., XIV., 386–388, 1902.)

Buchite, sandstones whose argillaceous or calcareous cement has been melted with more or less of the quartz grains into a glass by the contact influence of neighboring basalt. (Zirkel, Lehrbuch der Petrographie 3, 99, 1894.)

Buchnerite, a name proposed by Wadsworth for those peridotites, terrestrial and meteoritic, which consist of olivine, enstatite (bronzite) and augite. The name was given in honor of Dr. Otto Buchner, an authority on meteorites. Lithological Studies, 1884, p. 85.

Buchonite, a special name given by Sandberger to a nephelite-tephrite that contains hornblende. Sitzungsberichte d. Berl. Akad. Wiss., July, 1872, 203; 1873, vi.

Buhrstone, a silicified, fossiliferous limestone, with abundant cavities which were formerly occupied by fossil shells. Its cellular character and toughness occasioned its extensive use as a millstone in former years.

Bysmalith, a name suggested by J. P. Iddings for an igneous intrusion that forms a huge cylindrical mass or plug, with length and width approximately the same, but of relatively great height. Journal of Geology, VI., 704.

C

Calcarenite, a name suggested by A. W. Grabau for a "limestone or dolomite composed of coral or shell sand or of lime sand derived from the erosion of older limestones." The name is from the Latin for lime and sand. Bull. Geol. Soc. Amer., XIV., 349, 1903.

Calcilutite, a name suggested by A. W. Grabau for a limestone or dolomite made up of calcareous rock flour, the composition of which is typically non-siliceous, though many calcilutites have an intermixture of clayey material. The word is from the Latin for lime and mud. Bull. Geol. Soc. Amer., XIV., 350, 1903.

Calcirudite, a name suggested by A. W. Grabau for a "limestone or dolomite composed of broken or worn fragments of coral or shells or of limestone fragments, the interstices filled with lime, sand or mud, and with a lime cement." The word is derived from the Latin for lime and rubble. Bull. Geol. Soc. Amer., XIV., 349, 1903.

Calc-schist, schistose rocks, rich in calcite or dolomite and forming intermediate or transitional rocks between the mica-schists and crystalline limestones. See p. 129. Compare cipolin.

Camptonite, a name given by Rosenbusch to certain dike rocks, having in typical cases the mineralogical composition of diorites, *i. e.*, with dark brown hornblende, plagioclase, magnetite, and more or less augite. They are often porphyritic in texture, and may even have a glassy groundmass. Without the microscope camptonites usually appear as dark basaltic rocks with a few shining crystals of hornblende or augite; their determination is essentially microscopic. Intimately associated with the camptonites of typical composition have been found others corresponding to all varieties of basaltic rocks. Such with prevailing augite have been called augite-camptonite. The name camptonite is derived from the township of Campton, in the Pemigewasset Valley, N. H. The original camptonites were discovered near Livermore Falls, on the Pemigewasset river, many years ago, by O. P. Hubbard. They were microscopically described by G. W. Hawes in 1878, and on this determination Rosenbusch based the name. They, or their near relatives, have often intimate associations with nephelite syenites. (See also, monchiquite, fourchite, ouachitite.) Camptonites are especially abundant throughout the Green Mountains and near Montreal. G. W. Hawes, Amer. Jour. Sci., 1879, XVII., 147. H. Rosenbusch, Massige Gesteine, 1887, 333. Bulletin 107, U. S. Geol. Surv.

Cancrinite, the name of the mineral is sometimes prefixed to the names of rocks containing it, as cancrinite-syenite.

Carbonolite, Wadsworth's name for carbonaceous rocks. Rept. State Geol. Mich., 1891–92, p. 93.

Carmeloïte, a name given by A. C. Lawson to a group of eruptive rocks at Carmelo Bay, Calif., which are intermediate between the basalts and andesites. They range in silica from 52 to 60 per cent., have augite and plagioclase for phenocrysts; and a peculiar, orthorhombic, hydrated silicate of iron, lime, magnesia and soda, which is a secondary mineral after some original, probably olivine. The secondary mineral has been called Iddingsite. Bull. Geol. Dept. Univ. of Calif., I., 29, 1893.

Cascadite, an adaptation by Rosenbusch into the forms of the customary nomenclature of Pirsson's term cascadose, of the quantitative system. The name is derived from Cascade Co., Mont., where the rock, which is a variety of minette, occurs. (Bull. U. S. Geol. Survey, 237, p. 149. Rosenbusch, Mikros. Phys., 4th ed., II., 698.)

Cataclastic, a structural term applied to those rocks that have suffered mechanical crushing in dynamic metamorphism. Compare autoclastic.

Catawberite, a name given by O. Lieber to a rock in South Caro-

lina that is an intimate mixture of talc and magnetite. Gangstudien, III., 353, 359.

Catlinite, a local name in Minnesota for a red, siliceous argillite, presumably of Cambrian age, that was used by the Indians for pipe bowls. C. T. Jackson, Amer. Jour. Sci., 1839, 388.

Catogene, *i. e.*, sedimentary rocks, whose particles have sunk from above downward.

Cement, the material that binds together the particles of a fragmental rock. It is usually calcareous, siliceous or ferruginous. See p. 96. The word is also used in gold-mining regions to describe various consolidated, fragmental aggregates, such as breccia, conglomerate and the like, that are auriferous.

Chalk, a marine, calcareous and excessively fine, organic sediment usually consolidated.

Charnockite, a name given by T. H. Holland to an ancient series of hypersthenic gneisses in India and only intended for local use. Memoirs Geol. Survey India, XXVIII., 130, 1900.

Cherokite, a name derived from the Cherokee, Mississippian limestone of southwest Missouri and coined by W. P. Jenney to describe the dense, hard, brown or drab, silicified, residual sands, which constitute the cement of the chert breccias in the zinc mines of the Joplin district. (Trans. Amer. Inst. Min. Eng., 22: 195, 1894.)

Chert, a compact, siliceous rock formed of chalcedonic or opaline silica, one or both, and of organic or precipitated origin. See pp. 116, 117. Cherts often occur distributed through limestone, affording cherty limestones. Flint is a variety of chert. Cherts are especially common in the Lower Carboniferous rocks of southwest Missouri.

Chibinite, a name derived from the Russian designation of the Finnish locality, better known among petrographers as Umptek, and applied by W. Ramsay to a variety of nephelite-syenite. It is a coarsely crystalline, aggregate of microperthite, nephelite, ægirite, titanite, eudialyte, lamprophyllite and rarer minerals. (Rosenbusch, Mikros. Physiographie, 4th ed., II., 231.)

Chlorite, a general name for the green, secondary, hydrated silicates, which contain alumina and iron, and which are especially derived from augite, hornblende and biotite. Chlorite is used as a prefix for various names of rocks that contain the mineral, such as chlorite schist. The name is coined from the Greek word for green.

Chlorophyr, a name given by A. Dumont to certain porphyritic quartz diorites near Quenast, Belgium. See Delesse, Bull. Soc. Geol. de France, 1850, 315.

Chondri, the rounded and ellipsoidal grains of silicates which are characteristic of meteorites. In section they suggest grains of wheat or barley, packed together, a fact which suggested the name from the Greek.

Chonolith (or chonolite), a name for an irregularly shaped mass of intrusive rock, coined by R. A. Daly from the Greek words for mold (in which metal is cast) and rock. "An igneous body (*a*) injected into dislocated rock of any kinds stratified or not; (*b*) of shape and relations irregular in the sense that they are not those of a true dike, vein, sheet, laccolith, bysmalith or neck; and (*c*) composed of magma either passively squeezed into a subterranean, orogenic chamber or actively forcing apart the country-rocks. Jour. of Geology, XIII., 499, 1905.

Ciminite, a name derived from the Monti Cimini in Italy, and given by H. S. Washington to a group of lavas, intermediate between trachytes and basalts. They are porphyritic in texture and are characterized by the presence of alkali feldspar and basic plagioclase, augite and olivine, with accessory magnetite and apatite. Biotite and hornblende are either absent or are insignificant. They range from 54 to 57 SiO_2, 5–9 CaO, and 3–6 MgO. Journal of Geology, V., 351, 1897. Compare Latite.

Cipolin, a marble charged with mica, usually of the variety phlogopite and forming a transition between marbles and mica-schists, two rocks which are often associated.

Clastic, a descriptive term applied to rocks formed from the fragments of other rocks; fragmental.

Clay, a general name for the fine, aluminous sediments that are plastic. Though usually soft, they may be so hard as to need grinding before the plasticity manifests itself, as in numerous fire clays. See p. 101.

Clay-ironstone, the argillaceous variety of spathic iron ore which forms concretions and beds in the shales of coal measures.

Clay slate, metamorphosed clay, with new cleavages developed by pressure and shearing. The term is used in distinction to mica-slate, and other slaty rocks. See p. 146.

Claystone-porphyry, an old and somewhat indefinite name for those porphyries whose naturally fine groundmass is more or less kaolinized so as to be soft and earthy, suggesting hardened clay

Clinkstone. See Phonolite.

Comagmatic, a region or petrographic province whose igneous rocks possess some marked, common characteristic such as relatively high percentages of soda or potash or lime.

Comendite, a variety of rhyolite, containing phenocrysts of sanidine, quartz and ægirite, in a granophyric and spherulitic groundmass. Hornblende and some blue, soda-amphibole, together with zircon, magnetite, titanite, tridymite, and plagioclase occur as accessories. The name was given by Bertolis, an Italian geologist, from a locality on the island of San Pietro, Sardinia. Rend. Roy. Acad. Lincei, IV., 48, 1895. Compare Paisanite.

Complementary Rocks, a term suggested by W. C. Brögger for the basic rocks, which, usually in the form of dikes, accompany larger intrusions of more acidic types, and "complement" them in a chemical sense. Quar. Jour. Geol. Soc., L., 15, 1894. Compare Lamprophyre, Oxyphyre and Radial Dikes.

Composite dike, a dike formed by two intrusions of different ages which have entered the same fissure (W. Judd, Quar. Jour. Geol. Soc., 1893, 536).

Concretions, spheroidal or discoid aggregates formed by the segregation and precipitation of some soluble mineral like quartz or calcite around a nucleus, which is often a fossil.

Cone-in-cone, a curious structure, occasionally met in clay rocks, whereby two opposing and interlocking sets of cones or pyramids are developed, with their axes parallel and their bases in approximately parallel surfaces.

Conglomerate, consolidated gravel. See p. 96.

Consanguinity, a term used by Iddings to describe the genetic relationship of those igneous rocks which are presumably derived from a common, parent magma. See p. 91, and Bull. Phil. Soc. Washington, XI., 89.

Consertal, a texture in an igneous rock, composed of irregularly shaped crystals, closely fitted together. (Jour. Geol., 14: 700, 1906.)

Contact, the place or surface where two different kinds of rocks come together. Although used for sedimentary rocks, as the contact between a limestone and sandstone, it is yet more characteristically employed for the border between igneous intrusions and their walls. The word is of wide use in western mining regions on account of the frequent occurrence of ore-bodies along contacts. On contact-metamorphism, see pp. 125–130.

Coquina, a fragmental limestone consisting of bits of shells, cemented together in a loosely textured aggregate. The rock is common in Florida.

Cordierite, a synonym of iolite or dichroite, employed as a prefix to those rocks that contain the mineral, as cordierite-gneiss.

Cornubianite, a name coined by Blase from the classic name for Cornwall, England, to describe a contact hornfels, consisting of andalusite, mica and quartz. It was proposed as a substitute for an earlier but indefinite term proteolite. Bonney suggests restricting cornubianite to tourmaline hornfels. Quar. Jour. Geol. Soc., 1886, 104.

Corona-structure. See Reaction-rims.

Corrasion, geological term for the wearing away of rocks by grit suspended in moving water or air: to be distinguished from erosion.

Corroded Crystals, phenocrysts that after crystallization are more or less reabsorbed or fused again into the ma ma.

Corsite, a name applied by Zirkel to the orbicular or spheroidal diorite from Corsica: synonym of napoleonite. Lehrb. d. Petrographie, 1896, II., 133, 320.

Cortlandtite, a special name given by G. H. Williams to a peridotite that consists chiefly of hornblende and olivine and that occurs in the so-called Cortlandt series of igneous rocks in the township of Cortlandt, just south of Peekskill, on the Hudson River. This rock had been previously called hudsonite by E. Cohen, a name rejected by Williams because already used for a variety of pyroxene. Amer. Jour. Sci., Jan., 1886, 30.

Corundolite, Wadsworth's name for rocks composed of corundum or emery. Rept. State Geol. Mich., 1891–92, p. 92.

Corundum, the name of the mineral is sometimes prefixed to the names of rocks containing it; as corundum-syenite.

Covite, a name derived from Magnet Cove, Ark., and suggested by H. S. Washington for a leucocratic, holocrystalline combination of orthoclase (alkali-feldspar) and less nephelite, with hornblende and ægirite-augite, and of granitic texture. A typical analysis is given in the reference. Jour. Geol., IX., 612–615, 1901. The rock had been previously described as a "fine-grained syenite," by J. F. Williams.

Crenitic, a word derived from the Greek for spring, and especially used by T. S. Hunt for those rocks, which were thought by him to have come to the surface in solution and to have been precipitated. He used the so-called "crenitic hypothesis" to explain certain schists whose feldspars were supposed to have been originally zeolites, but his views have received slight, if any, support. Proc. Roy. Soc. Canada, Vol. II., Sec. III., 1884. Reprint, p. 25. Crenitic is also used by W. O. Crosby to describe those mineral veins which have been deposited by uprising springs. Technology Quarterly, April, 1894, p. 39.

Cross-bedding, or **Cross-stratification,** descriptive terms applied to those minor or subordinate layers in sediments that are limited to single

beds, but that are inclined to the general stratification. They are caused by swift, local currents, deltas, or swirling wind-gusts, and are especially characteristic of sandstones, both aqueous and eolian. See pp. 94, 95.

Crustification, the English equivalent of a term suggested by Posepny for those deposits of minerals and ores that are in layers or crusts and that, therefore, have been distinctively deposited from solution. Trans. Amer. Inst. Min. Eng., XXIII., 207, 1893.

Crypto-crystalline, formed of crystals of unresolvable fineness, but not glassy. A submicrosopical crystalline aggregate.

Crystallites, the term is most properly applied only to small, rudimentary or embryonic crystals, not referable to a definite species, but it is also used as a general term for microscopic crystals.

Cumberlandite, a name derived from Iron Mine Hill in the town of Cumberland, R. I., proposed by Wadsworth for the ultra-basic, igneous rocks, forming the hill. It is an aggregate of titaniferous magnetite, plagioclase, olivine and secondary minerals, but contains from 40–45 per cent. iron oxides and about 10 per cent. TiO_2. Lithological Studies, 1884.

Cumulites, Vogelsang's name for spherulitic aggregates of globulites. Die Krystalliten, 1875.

Cumulophyric, a porphyritic texture in which the phenocrysts are in irregular groups. (Jour. Geol. 14: 703, 1906.)

Cuselite, Rosenbusch's name for a peculiar variety of augite-porphyrite from Cusel, in the Saar basin. Massige Gest., 503, 1887.

D

Dacite, quartz-bearing andesites. The name was suggested by the ancient Roman province of Dacia, now in modern Hungary See p. 56.

Dahamite, a name derived from Dahamis, a place on the island of Socotra, and given by A. Pelikan to a dike rock of brown color, conpact texture with red phenocrysts of tabular albite or albite-oligoclase. The mineralogical composition as shown by recasting an analysis is albite, 43.8; anorthite, 2.8; orthoclase, 12.2; quartz, 31.5; riebeckite, 6.8. The rock appears to be related to paisanite. Denkschr. d. mat. natur. wiss. Classe d. k. Akad. d. Wiss. Vienna, LXXI., 1902. Amer. Jour. Sci., Nov., 1902, 397.

Damourite-schist, a micaceous schist whose micaceous mineral is damourite. Much the same as hydro-mica schist. See p. 139.

Dedolomitization, the alteration of a dolomite into some other rock, as into a serpentine.

Dellenite, a name proposed by Brögger for an intermediate group of effusive rocks, between the dacites and the liparites (rhyolites). The name is derived from Dellen, Helsingland, Sweden. Die Triadische Eruptionsfolge bei Predazzo, p. 60, and footnote to p. 59. Compare Toscanite.

Desmosite, a banded contact rock developed from shales and slates by intrusions of diabase. Compare spilosite and adinole. See Zincken, Karsten und v. Dechen's Archiv, XIX., 584, 1845.

Detritus, a general name for incoherent sediments, produced by the wear and tear of rocks through the various geological agencies. The name is from the Latin for "worn."

Devitrification, the process by which glassy rocks break up into definite minerals. The latter are usually excessively minute but are chiefly quartz and feldspars.

Diabase, igneous rocks, in sheets or dikes, consisting essentially of plagioclase, augite and magnetite, with or without olivine, and possessing a texture often called ophitic, but which may, perhaps, be better described as diabasic. The feldspars are lath-shaped and automorphic while the augite is xenomorphic and packed in their interstices. See p. 77, and also Ophitic. Diabase has had a somewhat variable significance during its history, but with the final exit of the time-element in the classification of igneous rocks its present meaning is generally accepted as above given. In a suggested system for the classification of the igneous rocks J. E. Spurr has used it as a group name for those igneous rocks whose chief feldspar is a plagioclase belonging to the labradorite-anorthite series. Subdivisions are then based on textures. 20th Ann. Rep. U. S. Geol. Surv., Part 7, pp. 211–216. Nevertheless the statement above remains correct. Diabase is often used as a prefix for double names, as diabase-aphanite, diabase-gabbro, etc.

Diabase-porphyrite, a porphyrite whose groundmass is a finely crystalline diabase, and whose phenocrysts are prevailingly plagioclase. It is contrasted with augite-porphyrite, whose phenocrysts are prevailingly augite.

Diagenesis, the solidification of clastic rocks by static metamorphism not involving much if any recrystallization. The change of muds to shales, and of clays to slates are illustrations. The term has been especially brought forward in later years by Joh. Walther.

Diallage, the variety of monoclinic pyroxene which in addition to the prismatic cleavages, has others parallel to the vertical pinacoids. Used also as a prefix to many rocks containing the mineral.

Diaschistic. See Aschistic.

Diatomaceous earth, rocks essentially formed of the abandoned frustules of the microscopic organisms called diatoms.

Dichroite, see under cordierite.

Dikes, spelled also dykes, intrusions of igneous rocks in fissures; not to be confounded with veins which are precipitated from solution.

Diluvium, a name formerly applied to the unsorted and sorted deposits of the Glacial period, as contrasted with the later water-sorted alluvium. Compare Alluvium.

Diorite, a granitoid rock consisting essentially of plagioclase and hornblende. More or less biotite is usually present, which may even replace the hornblende, yielding mica-diorite; augite also often appears. Acidic varieties with quartz are called quartz-diorites. See pp. 59, 64. Diorite is often used as a prefix for porphyritic or other rocks related to diorite. The name is from the Greek, to distinguish, in reference to the contrasts of the hornblende and feldspar, and was given by Hauy in 1822. Traité de Mineralogie, IV., 451. Diorite has been used by J. E. Spurr as a group name for those igneous rocks whose chief feldspar is a plagioclase belonging to the oligoclase-andesine series. 20th Ann. Rep. U. S. Geol. Survey, Part 7, pp. 204, 209. There is also a well-marked disposition among petrographers in general, to imply a rock with acidic plagioclase by diorite, and one with more basic varieties by gabbro. Cf. H. W. Turner, 17th Ann. Rep. U. S. Geol. Survey, Part 1, 730.

Diorite-porphyrite, a porphyrite whose groundmass is a finely crystalline diorite, and whose phenocrysts are prevailingly plagioclase. It is contrasted with hornblende-porphyrite, whose phenocrysts are prevailingly hornblende.

Dipyr, a variety of scapolite, often used as a prefix to the names of rocks that contain the mineral.

Disthene, synonym of cyanite, sometimes used as a prefix in rock names.

Ditroite, a nephelite syenite from Ditro in Hungary, especially rich in blue sodalite. See p. 52.

Do, the first syllable of dominant; used as a prefix in the nomenclature of the Quantitative System of Classification. Thus *dofemic* means that the femic, or ferrogmagnesian minerals predominate; *dosalic* that the silica-alumina minerals, quartz and feldspars do the same. Various other terms are also employed which will be found in the treatise of Cross, Iddings, Pirsson and Washington.

Dolerite, coarsely crystalline basalts. The word has had a somewhat variable meaning during its history and among different peoples. The

English use it interchangeably with diabase; indeed the definitions given here justify this usage, except that the characteristic texture of diabase is not essential to this definition of dolerite. But the diabasic texture is more of a microscopic feature than a megascopic. Dolerite is from the Greek for deceptive, and was given by Hauy in allusion to its application to later rocks, that could not be distinguished from older greenstones. The name is a long standing indictment of the time element in the classification of igneous rocks.

Dolomite, is applied to those rocks that approximate the mineral dolomite in composition. Named by Saussure, after Dolomieu, an early French geologist. See p. 108.

Dolomitization or **Dolomization,** the process whereby limestone becomes dolomite by the substitution of magnesian carbonate for a portion of the original calcium carbonate. If the $MgCO_3$ approximates the 45.65 per cent. of the mineral dolomite, there is great shrinkage in bulk, leading to the development of porosity and cavities up to 11 per cent. of the original rock.

Domite, a more or less decomposed trachyte from the Puy de Dome in the French volcanic district of the Auvergne. The typical domite contains oligoclase and is impregnated with hematite.

Drift, a general name for the unsorted deposits of the glacial period. Where subsequently worked over by water they are called modified drift.

Dunite, a member of the peridotite group that consists essentially of olivine and chromite. It was named from the Dun Mountains in New Zealand, the original locality, but it also occurs in North Carolina. The name was given by v. Hochstetter in 1859. Geol. v. Neu Seeland, 218, 1864.

Durbachite, a name given to a basic development at the outer border of a granite intrusion in Baden. It has the general composition of mica syenite. The name was given by Sauer, Mitth. d. grossh. bad. Geol. Landesanstalt, II., 233.

Dykes, see dikes.

Dynamometamorphism, a general term for those metamorphic changes in rocks that are produced by mechanical as distinguished from chemica process, but the former are seldom unattended by the latter. See p. 131.

Dysyntribite, a name given by C. U. Shepard, Amer. Assoc. Adv. Sci., 1851, 311, to a mineral or rock in St. Lawrence Co., N. Y., which is a hydrated silicate of aluminium and potassium, and is related to pinite; the same means hard to crush. Compare parophite. See also,

Smith and Brush, Amer. Jour. Sci., ii., XVI., 50, and C. H. Smyth Jour. of Geol., II., 678, 1894.

E

Eclogite, a more or less schistose metamorphic rock, consisting of a light-green pyroxene (omphacite), actinolite (var. smaragdite) and garnet. Rarely found in America. See p. 143 and anal. 6, p. 142 The name is from the Greek to select, in reference to its attractive appearance.

Effusive, a name applied to those rocks that have poured out in a molten state on the surface and have there crystallized, *i. e.*, volcanic rocks. See p. 16.

Ehrwaldite, a basic dike-rock from Ehrwald, consisting of phenocrysts of altered olivine, biotite, barkevicite and titanaugite, in a groundmass of augite-microlites and altered glass. (Rosenbusch, Mikr. Phys., II., 701. The name was given by Pichler.)

Ekerite, a name given by W. C. Brögger to a granite, rich in alkalies and having arfvedsonite as its prevailing dark silicate. (Nyt. Mag. f. Naturvid., XLIV., 114, 1906.) Additional details are given by H. Rosenbusch. (Mikros. Phys., 4th ed., II., 525.)

Elæolite or **Eleolite,** a name formerly current for the nephelite of pretertiary rocks. It is best known in the rock-name eleolite-syenite, a synonym of nephelite-syenite, but the latter is preferable. See nephelite-syenite.

Elvan, Cornish name for dikes of quartz-porphyry or of granite-porphyry.

Endomorphic, used as a descriptive adjective for those phases of contact-metamorphism that are developed in the intrusive itself. It is synonymous with internal as used on p. 125.

Enstatite, the variety of orthorhombic pyroxene with less than 5 per cent. FeO. It is largely used as a prefix to the names of rocks that contain the mineral.

Eocrystal, see under Brotocrystal.

Eolian, fragmental rocks, accumulated through the agency of the wind. See p. 99.

Eorhyolite, eobasalt, etc., a series of names proposed by O. Nordenskjoeld for the older equivalents of the rhyolites, basalts, etc. The terms are practically equivalent to aporhyolite, apobasalt, etc., but the latter have priority. Bull. Geol. Inst. Univ. of Upsala, I., 292, 1893.

Epi, the Greek proposition for upon and used as a prefix in this sense.

Epidiabase, a name proposed by Issel as a substitute for epidiorite

because believed to be more appropriate. Liguria geologica, I., 324, 1892. Cf. epidiorite.

Epidiorite, a name applied to dikes of diabase, whose augite is in part altered to green hornblende. The name was coined before it was understood that the hornblende was secondary in this way. It was first applied by Gümbel in 1879 to a series of narrow dikes that cut Cambrian and Ordovician strata in the Fichtelgebirge. The name emphasizes their later age than the typical pre-Cambrian diorites, but its significance has been expanded in later years.

Epidosite, rocks largely formed of epidote. The epidote seems generally to be produced by the reactions of feldspars and bisilicates upon each other during alteration.

Epidote, the name of the mineral is often prefixed to the names of rocks containing it. As a rule, the presence of epidote indicates the advance of alteration.

Epigenetic, *i. e.*, developed upon; specifically used for those ore-deposits which are precipitated upon preëxisting rocks, as in veins. The antithesis is syngenetic or the ore-bodies which are coincident in origin with the containing rocks, such as the basic segregations of titaniferous magnetite in members of the gabbro family.

Equant, those textures of igneous rocks which consist of equidimensional crystals. (Jour. Geol., 14: 698, 1906.) Its varieties are cuboidal, polyhedral, spheroidal, equant anhedral, equant subhedral.

Equigranular, igneous rocks, composed chiefly of crystals of like orders of magnitude. (Jour. Geol., 14: 698, 1906.) The opposite term is inequigranular.

Erlan or **Erlanfels,** a name proposed by Breithaupt for metamorphic rocks, which consist essentially of augite, *i. e.*, augite schists. The name is derived from the iron-furnace at Erla, near Crandorf, Saxony.

Erosion, geological term for the process of the removal of loose materials in suspension in moving water or in wind.

Eruptive, the name ought properly to be only applied to effusive or volcanic rocks, but it is often used as a synonym of igneous.

Essexite, a name derived from Essex County, Mass., and applied by J. H. Sears to a peculiar rock, occurring with the nephelite-syenite of Salem Neck. It is an intermediate rock among the nephelite-syenites, the diorites, and the gabbros, and contains labradorite, orthoclase, and more or less nephelite or sodalite, together with augite, biotite, barkevicite, olivine, and apatite. Bulletin Essex Institute, XXIII., 146, 1891, H. S. Washington, Journal of Geology, VII., 53, 1899.

Esterellite, a name given by A. Michel-Levy to a variety of diorite-porphyry from Esterel, France. The rock shows some peculiarities of chemical composition which have given it special interest in discussions relating to differentiation. Bull. Service Carte geol. de la France, LVII., 21, 1897, Bull. Soc. Geol. de la France (3), XXIV., 123.

Eucrite, a name given by G. Rose to rocks and meteorites that consist essentially of anorthite and augite. The term is practically obsolete. Pogg. Annalen, 1835, I., 1.

Eudialyte, the name of the mineral is sometimes prefixed to the rare nephelite-syenites that contain it.

Euhedral, with well-developed faces; applied to phenocrysts or smaller components of an igneous rock which are completely bounded by crystal faces. (Jour. Geol., 14: 698, 1906.) Much the same as automorphic and idiomorphic. The opposite term is anhedral; an intermediate one subhedral.

Euktolite, a name derived from the Greek words for "desired rock" and given by H. Rosenbusch to one which filled a gap in his classification of rocks. Sitzungsber. der k. p. Akad. Wissensch., Berlin, VII., 110, 1899. The same rock had been previously named venanzite (which see). Cf. Amer. Jour. Sci., May, 1899, 399.

Eulysite, a name given by Erdmann to rocks interlaminated with the gneisses of Sweden, and consisting of olivine, green pyroxene and garnet. Neues Jahrb., 1849, 837.

Euphotide, the name chiefly used among the French for gabbro. It was given by Hauy, and is derived from the Greek words for well and light, in allusion to its pleasing combination of white and green.

Eurite, used among the French as a synonym of felsite, but also applied to compact rocks, chiefly feldspar and quartz, such as some granulites. The name was first given by Daubisson to the groundmass of porphyries, because of their easy fusibility compared with hornstone or flint.

Eutaxitic, a general name for banded volcanic rocks. The banding is due to the parallel arrangement of portions of the rock that are contrasted either in mineralogy or texture.

Eutectic, a term now used by both petrologists and metallographers, for those molten or solidified mixtures of two or more compounds or metals, which when considered as solutions one of the other, mutually saturate each other or one another. In alloys, when two metals are melted together, the fusing point of the combination is lower than the fusing point of either. By suitable proportions a mixture is finally reached which has the lowest possible fusing point. The same is true

of minerals. If now we imagine such a mixture in a molten condition and cooling, it will remain molten down to the minimum temperature. On passing this mark both must crystallize simultaneously and yield interpenetrating or at least intimately mixed crystals. These are called eutectics. Graphic granite is the most familiar illustration in rocks. It contains approximately 25 per cent. quartz and 75 per cent. orthoclase.

Evergreenite, a name derived from the Evergreen mine, at Apex, Gilpin Co., Colo., and given by E. A. Ritter to a dike of general granitoid texture, but with micropegmatitic and porphyritic phases. The principal minerals are quartz, orthoclase, albite (both at times forming microperthite), ægirite, enstatite and diallage. The dike also contains chalcopyrite and bornite as original, rock-making minerals and coördinate in amount with the normal components. The copper minerals give the dike economic value. The dike is thus practically a nordmarkite with added metallic sulphides. Bull. Amer. Inst. Min. Eng., No. 19: 33, 1908.

Exomorphic, a descriptive term for those changes which are produced by contact-metamorphism in the wall rock of the intrusion; the antithesis of endomorphic. It is synonymous with external as used in p. 125.

Extrusive, synonym of effusive, much used in America.

F

Fabric, the shape and arrangement of the crystalline and non-crystalline parts of an igneous rock. (Jour. Geol., 14: 693, 1906.) Together with crystallinity and granularity (size of components) fabric completes the three features of texture.

Fahlband, a name, originally applied in Norway, to bands of metamorphic rocks, which are impregnated with metallic sulphides, such that the out-crop is rusty, the name meaning foul or rotten layer. The Fahlbands are of especial importance in the Kongsberg region, where they exercise an enriching influence upon the veins which cross them.

Farrisite, a name derived from Lake Farris in Norway, and applied by Brögger to a very peculiar rock, which is as yet known only in one small dike. The rock is finely granular in texture and consists of some soda-bearing, but not sharply identified, tetragonal mineral related to melilite, together with barkevicite, colorless pyroxene, biotite, serpentinous pseudomorphs after olivine, magnetite and apatite. Das Ganggefolge des Laurdalits, 66, 1898.

Feldspar, the name of the mineral is often prefixed to the names of those rocks that contain it, such as feldspar-porphyry, feldspar-basalt, etc.

Feldspathoids, silicates of alumina and an alkali or alkaline earth, that are practically equivalent to feldspars in their relations in rocks. The principal ones are nephelite, leucite and melilite, but sodalite, nosean, hauyne, analcite and even muscovite could perhaps be also considered such, although their composition may, in instances, vary from the above.

Felsite, the word was first applied in 1814 by Gerhard, an early geologist, to the fine groundmasses of porphyries. These were recognized to be fusible as distinguished from hornstone, which they resembled (compare eurite). Felsite is now especially used for those finely crystalline varieties of quartz-porphyries, porphyries or porphyrites that have few or no phenocrysts, and that, therefore, give but slight indications to the unaided eye of their actual mineralogical composition. The microscope has shown them to be made up of microscopic feldspars, quartzes and glass. Petrosilex has been used as a synonym. See p. 17.

Felsitic, has been employed as a megascopic term in the preceding pages to describe those textures which are characteristic of felsites, *i. e.*, micro-crystalline, but without phenocrysts. See p. 17. It is often used also to describe the groundmasses of truly porphyritic rocks, that are micro-crystalline, but clearly not glassy. In this sense we have felsite-porphyry, felso-liparite, felso-dacite, etc.

Felsophyre, a contraction for felsite-porphyry.

Felspar, the current spelling of feldspar among the English. It is based on an old typographical error in Kirwan's Mineralogy, I., 317, 1794, now, however, firmly established in general usage.

Femic, a very useful term coined by the authors of the Quantitative System, from the first letters of ferrum amd magnesium, as used in ferromagnesian. Femic means therefore rich in ferromagnesian minerals, as is the case with the basic igneous rocks. Its antithesis is salic.

Fergusite, a name derived from Fergus Co., Montana, and coined by L. V. Pirsson to describe a granitoid intrusive rock consisting of dominant leucite, now represented by pseudoleucite and subordinate augite. The accessories are apatite, iron ores, biotite, and sporadic olivine. Fergusite is the deep-seated representative of the leucitites. The typical locality is the Arnoux stock of the Highwood mountains. (Bulletin 237, U. S. Geol. Survey, 89, 1905.)

Ferrite, microscopic crystals of iron oxide.

Ferrolite, Wadsworth's name for rocks composed of iron ores. Rept. State Geol. Mich., 1891–92, p. 92.

Fibrolite, synonym of sillimanite and sometimes used as a prefix to rock names.

Fiorite, siliceous sinter, named from Mt. Santa Fiora, in Tuscany.

Firn, Swiss name for the granular, loose or consolidated snow of the high altitudes before it forms glacial ice below.

Flaser-structure, a structure developed in granitoid rocks and especially in gabbros by dynamic metamorphism. Small lenses of granular texture are set in a scaly aggregate that fills the interstices between them. It appears to have been caused by shearing that has crushed some portions more than others, and that has developed a kind of rude flow-structure.

Flint, a compact and crypto-crystalline aggregate of chalcedonic and opaline silica. Chert and hornstone are synonyms. See pp. 116, 117.

Float, a term much used among Western miners for loose, surface deposits, which are usually somewhere near their parent ledges.

Flow-structure, a structure due to the alignment of the minerals or inclusions of an igneous rock so as to suggest the swirling curves, eddies and wavy motions of a flowing stream. It is caused by the chilling of a flowing, lava current. Fluxion-structure is synonymous.

Foliation, the banding or lamination of metamorphic rocks as distinguished from the stratification of sediments.

Forellenstein, a variety of olivine-gabbro, consisting of plagioclase, olivine and more or less pyroxene. The dark silicates are so arranged in the lighter feldspar as to suggest the markings of a trout. (German, Forelle.)

Formation, as defined and used by the U. S. Geological Survey, is a large and persistent stratum of some one kind of rock. It is also loosely employed for any local and more or less related group of rocks. In Dana's Geology it is applied to the groups of related strata that were formed in a geological period.

Fortunite, a dike rock from Fortuna in the Spanish province of Murcia, originally named by Ramón Adán de Yarza. (Bol. Com. del mapa geol. de España, 20, 1893.) In a glassy groundmass are found phenocrysts of olivine, phlogopite and apatite, together with so-called "belonites." The supposed absence of pyroxene led the author to separate it from Verite. A. Osann later identified the belonites as diopside, and demonstrated by chemical analysis that verite and fortunite are the same species. Osann's analyses also prove the phlogopite to be practically of the same composition as that from the Leucite Hills, Wyo. (Festschrift zum siebzigsten Geburtstage von Harry Rosenbusch, 1906, 263.)

Fourchite, a name proposed by J. Francis Williams for those basic dike rocks that consist essentially of augite in a glassy groundmass, *i. e.*,

dike-augitites. The name was suggested by Fourche Mountain, Ark., where they are abundant. Ann. Rep. Geol. Sur. Ark., 1890, II., 107.

Foyaite, a name originally applied to the nephelite syenite, with supposed hornblende, of Mt. Foya in the Monchique range of Portugal. Although the hornblende has since proved to be augite and ægirite, the name foyaite is still employed for nephelite syenite with hornblende. See p. 52.

Fragmental, a descriptive term for the rocks, such as sandstones and breccias, which are formed from fragments of preëxisting rocks. Clastic is synonymous.

Fraidronite, a name used by early French geologists for a variety of minette.

Freestone, a quarryman's name for those sandstones that submit readily to tool treatment.

Fruchtschiefer, German name for a variety of spotted, contact schists in the outer zone of the aureole. See p. 127.

Fuller's earth, a fine earth, resembling clay, but lacking plasticity. It is much the same chemically as clay, but has a decidedly higher percentage of water.

Fulgurite, little tubes of glassy rocks that have been fused from all sorts of other rocks by lightning strokes. They are especially frequent on exposed crags or mountain tops. The name is derived from the Latin for thunderbolt.

G

Gabbro, an Italian word formerly used for a rock composed of serpentine and diallage. It was later applied to igneous rocks, of granitoid texture, consisting of plagioclase and diallage, but as now employed, any monoclinic pyroxene may be present, with or without diallage. As the name of a group, it includes in addition to the rocks with monoclinic pyroxene, those with plagioclase and orthorhombic pyroxene as well; and even the peridotites and pyroxenites, from their close geological connection with the gabbros may conveniently be embraced. Although of the same mineral composition with gabbro, yet the peculiar and contrasted texture of diabase may be remarked. Intermediate types have even been called gabbro-diabase. See p. 78. A full review of the meaning and history of gabbro, by W. S. Bayley, will be found in Jour. of Geology, I., 435, Aug., 1893.

Gabbro-diorite, gabbro with hornblende which may, in fact, be secondary after augite. Intermediate rocks between true gabbros and diorites.

Ganggesteine, German for dike rocks.

Garéwaite, a porphyritic and very basic dike-rock, from the northern Urals. Phenocrysts of diopside are found in a ground mass, chiefly olivine, magnetite and chromite. Minor components are pyroxene and labradorite. (L. Duparc and F. Pearce, Comptes Rendus, CXXXIX., 154, 1894.)

Garganite, a name suggested by Viola and de Stefani for a dike rock in the Italian province of Foggia, which in the middle, with prevailing alkali-feldspar contains both augite and amphibole, *i. e.*, is a vogesite; on the edges it contains biotite, hornblende and olivine, and resembles kersantite. Boli. Roy. Com. Geol. d'Italia, 1893, 129.

Garnet-rock, a rock composed essentially of garnets.

Gauteite, a name derived from the Gaute valley, central Bohemia, and given by J. E. Hibsch to a leucocratic dike rock of porphyritic texture and trachytic habit. The phenocrysts are hornblende, augite, and abundant lime-soda feldspar. The groundmass is about 80 per cent. feldspar rods, with the remainder magnetite grains, small hornblendes, augites, biotites and a little colorless glass. The gauteite is regarded as a complementary dike-rock to neighboring camptonites and is believed to correspond to the deep-seated monzonites. Tsch. Mitth., XVII., 87, 1897.

Generations of minerals in an igneous rock refer to the groups of individuals that crystallize out at a definite period and in a more or less definite succession during cooling. The same species may have one, two, or very rarely three generations. See p. 21.

Geodes, hollow, rounded boulders lined with crystals projecting inward from the walls.

Geest, a name proposed by J. A. DeLuc in 1816 for "the immediate products of rock decay in situ." It is a provincial word for earth in Holland and northern Germany. Abrégé Geologique, Paris, 1816, 112, as quoted by W J McGee, 11th Ann. Rep. U. S. Geol. Survey, Part I., 279. Compare Laterite, Saprolite.

Geyserite, siliceous deposits from a geyser. See p. 116.

Gieseckite-porphyry, a nephelite porphyry from Greenland, whose nephelite phenocrysts are altered to the aggregate of muscovite scales, which was called gieseckite under the impression that it was a new mineral. Liebenerite porphyry is the same thing from Predazzo, in the Tyrol.

Giumarrite, a dike-rock, described as a hornblende-bearing augitite, and occurring near Giumarra, Sicily. (C. Viola, Boll. Roy. Com. geol. d'Italia, 1901.)

Gladkaite, a dike-rock in the dunite of the Gladkaia Sopka, northern

Urals. It has a finely crystalline texture and consists of acidic plagioclase, quartz, hornblende, biotite, apatite, magnetite and secondary epidote and muscovite. (L. Duparc and F. Pearce Comptes Rendus, CXL., 1614, 1905. See also Nature, June 22, 1905, p. 192.)

Glass, the amorphous result of the quick chill of a fused lava. See pp. 25, 26, 27, and for glassy texture, p. 16.

Glauconite, the green silicate of iron and potassium that is important in many green sands. See p. 103.

Glaucophane, a blue soda-amphibole found especially in certain, rare schists. See pp. 142, 143.

Globulite, spheroidal beginnings of crystals; believed by Vogelsang, to be the first recognizable elements of crystals, which could be observed with high powers especially when the crystallizing process was retarded by some thick medium such as glycerine.

Glomeroporphyritic, a textural term proposed by Tate for those porphyritic rocks whose feldspar phenocrysts are made up of an aggregate of individuals instead of one, large crystal. British Assoc. Adv. Sci., 1890, 814. Compare Ocellar.

Gneiss, a laminated or foliated granitoid rock that corresponds in mineralogical composition to some one of the plutonic rocks. The name originated among the Saxon miners. See p. 133.

Granite, in restricted signification is a granitoid, igneous rock consisting of quartz, orthoclase, more or less oligoclase, biotite and muscovite, but is widely used in a more general sense. The first three may also be combined with either of the micas alone, with hornblende or with augite. In its technical applications as a name of a building stone it is used for almost any crystalline rock composed of silicates, as contrasted with sandstones, slates, limestones and marbles. It is a very old term. See pp. 33–38.

Granitelle, a granite with comparatively little mica, so that it consists almost entirely of quartz and feldspar; binary granite. It has been also used by R. D. Irving for augite-granite. U. S. Geol. Surv., Monograph V., p. 115.

Granite-Porphyry, practically a quartz-porphyry with a coarsely crystalline groundmass and preponderating phenocrysts; an intermediate rock between granites and typical quartz-porphyries, having the same minerals as the former, but being porphyritic like the latter. The chief phenocrysts are, however, feldspars. See p. 31.

Granitite, a special name for biotite-granite. It is much the commonest of the granites.

Granitoid, used in preceding pages as a textural term to describe

those igneous rocks which are entirely composed of recognizable minerals of approximately the same size. It was suggested by granite, the most familiar of the rocks which show this characteristic. See p. 17. In the granitoid texture each kind of mineral appears in but one generation, and the individuals seldom have crystal boundaries.

Granodiorite, a term which has been given special currency by the usage of the U. S. Geological Survey, and which is employed for the intermediate rocks between granites and quartz-diorites. It is a contraction for granite-diorite and is a very useful rock name. Compare Adamellite.

Granolite, a name suggested by L. V. Pirsson for the igneous rocks described as granitoid on preceding pages. It is a shortening of granular rock and embraces the plutonic series from granite through peridotite. (See Jour. Geol., 7: 141, 1899.)

Granophyre, a descriptive term used in connection with microscopic study, to describe those groundmasses in quartz-porphyries and microgranites in which the quartz and feldspar crystals have simultaneously crystallized, so as to mutually penetrate each other. The several parts of one individual, though separated from one another, extinguish together between crossed nicols. Micropegmatitic is synonymous. See also micro-perthitic, micro-poicilitic, and micro-granitic.

Granulite, properly speaking a finely crystalline, laminated, metamorphic rock consisting essentially of orthoclase, quartz and garnet, but having also at times cyanite, hornblende, biotite or augite. The name means garnet rock (*i. e.*, German for garnet, Granat). The granulites are best developed in the mountains of Saxony. Sometimes the name is less correctly used for muscovite granite, or for granites containing little else than quartz and feldspar. See p. 136.

Graphic Granite, an old name for that variety of pegmatite consisting of bladed crystals of quartz contained in orthoclase. When cracked across the long axes of the quartzes, the V-shaped and spindle-shaped cross-sections, suggest the cuneiform inscriptions of the ancient alphabets, hence the name. (See p. 35.) The structure is due to the simultaneous crystallization of the two minerals. The quartzes neighboring to one another are parts of a single crystal. The containing orthoclase is a single crystal. The aggregate is one of the best available instances of an eutectic. (See Eutectic.) The same structure is developed microscopically and is called micro-pegmatitic, or granophyric, or simply micrographic.

Graphite, the name of the mineral is often prefixed to the names of rocks containing it, as graphite-gneiss, graphite-schist, etc.

Graywacke, an old name of loose signification, but chiefly applied to metamorphosed, shaly sandstones that yield a tough, irregularly breaking rock, different from slate on the one hand and from quartzite on the other. The components of graywacke may be largely bits of rocks, rather than fragments of minerals.

Greenschists, chlorite schists, which may, however, be of quite diverse origin. See p. 142.

Greenstone, an old field name for those compact, igneous rocks that have developed enough chlorite in alteration to give them a green cast. They are mostly diabases and diorites. Greenstone is partially synonymous with trap. It is often used as a prefix to other rock names.

Greisen, a granitoid but often somewhat cellular rock, composed of quartz and muscovite or some related mica, rich in fluorine. It is the characteristic mother rock of the ore of tin, cassiterite, and is in most cases a result of the contact action of granite and its evolved mineralizers. See p. 130.

Grit, coarse sandstone.

Grorudite, Brögger's name for a porphyritic, dike rock from Grorud, near Christiania, Norway. The phenocrysts are microcline and ægirite; the groundmass consists of rectangular orthoclase, quartz and ægirite. It is a variety of granite porphyry. Zeitsch. f. Krys., XVI., 65.

Groundmass, the relatively finely crystalline or glassy portion of a porphyritic rock as contrasted with its phenocrysts. Not to be confounded with basis, as will be seen by referring to the latter. On groundmass, see p. 17.

Gruss, the fragmental products of the weathering of granite in its passage to soil.

Guano, phosphatic accumulations, useful as fertilizers and chiefly derived from the excrement of sea-fowl, deposited on marine islands.

Gumbo, a name current in Western and Southern States for those soils that yield a sticky mud when wet.

Gypsum, the name of the mineral is also applied to its bedded deposits, which constitute sedimentary rocks in series, usually associated with rock-salt.

H

Halleflinta, a Swedish name for dense, compact metamorphic rocks, consisting of microscopic quartz, and feldspar crystals, with occasional phenocrysts and sometimes hornblende, chlorite, magnetite and hematite. They are associated with gneisses, but are of obscure origin.

Haloidite, Wadsworth's name for rock-salt. Rept. State Geol. Mich., 1891–92, p. 92.

Haplite, a name proposed by L. Fletcher for that variety of granite which consists of quartz and potash feldspar. The name is derived from the Greek for simple. An Introduction to the Study of Rocks. British Museum Guide-books, 1895, 58, 63, 102. Compare Binary granite.

Hard-pan, a name specially developed in the digging of auriferous placers, and applied to the layers of gravel which are usually present a few feet below the surface and which are cemented by limonite or some similar bond. They are therefore resistant. It is also used to describe boulder-clay, which is likewise difficult to excavate.

Harrisite, Harker's name for a granitoid igneous rock with olivine predominant over anorthite. Compare allivalite. The two are intermediate between peridotites and anorthosites. The name is derived from a locality in the Hebrides.

Harzburgite, a name proposed by Rosenbusch for those peridotites that consist essentially of olivine and enstatite or bronzite. Mass. Gest., 1887, 269. Saxonite was earlier proposed by Wadsworth (1884) for the same rock, and has priority.

Hatherlite, a name proposed by A. Henderson for a syenite from South Africa which has for its feldspar anorthoclase instead of orthoclase. Petrographical and Geological Investigations of certain Transvaal Norites, Gabbros, Pyroxenites, etc., 1898. Pilandite is a porphyritic phase of the same.

Hauyne, the name of the mineral is often prefixed to the names of those rocks that contain it, as hauyne-basalt, hauyne-trachyte, etc.

Hedrumite, a name proposed by Brögger for certain, syenitic rocks that are poor or lacking in nephelite, but that have a trachytic texture. Zeitschr. Krys., XVI., 40. Das Ganggefolge des Laurdalits, 183.

Hemithrene, Brogniart's name, current among the French, for certain dioritic rocks that have a large amount of calcite, presumably an alteration product.

Heptorite, a variety of monchiquite, containing in a colorless, isotropic groundmass, assumed to be a glass, basaltic augite, acicular hornblende and hauynite. It occurs as a finely crystalline, narrow dike on the contact of trachyte and graywackes in the Siebengebirge or Seven Mountains of the Rhine valley. The name is given by K. Busz and is based on the Greek equivalent of Siebengebirge. (Neues Jahrbuch, 1904, II., 86.)

Heronite, a name proposed by A. P. Coleman, for a dike rock, consisting essentially of analcite, orthoclase, plagioclase and ægirite, the analcite having the character of a base, in which the other minerals form radiating groups of crystals. The name is derived from the lo-

cality, Heron Bay, on the north shore of Lake Superior. Journal of Geology, VII., 1899, 431.

Heumite, a name proposed by W. C. Brögger for a dike rock, composed of minerals, too small to be recognized with the eye alone, but which under the microscope prove to be natronorthoclase, natronmicrocline, barkevicite, biotite, and in small amount, nephelite, sodalite and diopside. The accessories are apatite, magnetite, pyrite and titanite. The silica in two dikes was found to be respectively 47.10 and 48.46. The name was derived from Heum, a small town on Lake Farris. Das Ganggefolge des Laurdalits, 90, 1898.

Hiatal, see seriate.

Holocrystalline, a textural term applied to those rocks that consist entirely of crystlalized minerals as distinguished from those with more or less glass.

Holyokeite, a name derived from Mt. Holyoke, Mass., and suggested by B. K. Emerson for an almost purely feldspathic phase of the Triassic diabase, found in fragments in a volcanic breccia. The rock is 70 per cent. albite, with calcite (16.42), orthoclase (9.41), and ilmenite (1.63), as the principal remaining constituents. (Journal of Geology, X., 508, 1902.)

Hornblende, the name of the mineral is prefixed to many rock names.

Hornblendite, a granitoid, igeneous rock consisting essentially of hornblende and analogous to pyroxenite. See p. 83.

Hornfels, a dense, compact rock produced from slates by the contact action of some igneous intrusion, especially granite. Various microscopic minerals are developed in it. See p. 126.

Hornstone, synonym of flint and chert.

Horses, a miner's term for fragments of wall rock included in a vein.

Hudsonite, See cortlandtite.

Hyaline, a synonym of glassy, which is often prefixed to the name of volcanic rocks to signify a glassy development, as hyalo-rhyolites.

Hyalomelane, Hausmann's name for basaltic glass. The word is derived from the Greek for black glass.

Hybrid, Harker's name for igneous rocks, which result from the commingling of two distinct magmas or from the absorption of solid rocks by molten masses. They are contrasted with the products of differentiation. (Natural History of the Igenous Rocks, 333, 1909.)

Hydato, a syllable prefixed to lithological terms to indicate an origin through aqueous processes.

Hydatopneumatolithic, a term used in the discussion of certain ore deposits to describe their origin through the agency of water and vapors.

Hydrogenic, a general name proposed by A. W. Grabau for the rocks which are due to the agency of water. It is somewhat more literally comprehensive of the precipitates from solution, such as rock salts, stalagmitic marbles, etc., than is sedimentary. It forms a logical member of the sequence, pyrogenic; hydrogenic; atmogenic.

Hypabyssai, Brögger's term for those igneous rocks whose textures are transitional between the granitoid varieties of the deep-seated and the typical porphyritic or glassy varieties of the effusive. Dikes are the commonest illustrations but border facies of large masses are also included. The components tend to be automorphic and if porphyritic the rock is fully crystallized. (Eruptivgest. der Krist. Geb., 1: 123, 1894.)

Hypautomorphic, see under idiomorphic.

Hyperite, used in Sweden loosely for the rocks of the gabbro family, and in a restricted sense for olivine-norite.

Hypersthenite, a somewhat obsolete name for norite.

Hypidiomorphic, see under idiomorphic.

Hypohyaline, a partly glassy texture in an igneous rock. (Jour. Geol., 14: 693, 1906.)

Hysterobase, a name given by K. A. Lassen to the rock of a series of dikes, related to the diabases, but differing from them, in often having quartz, brown biotite, and brown hornblende, the last sometimes replacing the augite. There may be also some glass basis. Zeitschr. d. d. g. Gesellsch., XL., 204, 1888.

Hysterogenite, Posepny's term for mineral deposits derived from the débris of other rocks. The word means of subsequent or later deposition than in their original homes. Trans. Amer. Inst. Min. Eng., XXIII., 211. Compare idiogenite, xenogenite.

Hysteromorphous, a term suggested by Posepny for those ore deposits that have been formed from some other original deposits by the chemical and mechanical influences of the surface region. Trans. Amer. Inst. Min. Eng., XXIII, 331, 1893.

I

Idiogenites, a term suggested by Posepny to describe those ore deposits which are contemporaneous in origin with the wall rock. The word means of the same origin. Trans. Amer. Inst. Min. Eng., XXIII., 211, 1893. Compare xenogenite, hysterogenite.

Idiomorphic, a descriptive term for those component minerals of a rock that have their own crystal faces. Rarely all are of this character, and then the rock is called panidiomorphic. Again, some are, and others are not, giving the hypidiomorphic texture. The phenocrysts of

porphyritic rocks are most prone to be idiomorphic. When no minerals have their own crystal faces, as in most granites, the rock is allotriomorphic, as earlier explained. All these terms were suggested by Rosenbusch, Mass. Gest., 1887, but Rohrbach's automorphic and xenomorphic, as is stated under the former. have a year's priority and mean the same thing. The words are of chief importance in microscopic work.

Ijolite, a granitoid, nephelite rock, occurring in Finland and corresponding in mineralogy to the nephelinites. It contains chiefly nephelite and pyroxene. The name is derived from the Iijoki River, Finland, and was given by Ramsay and Berghell. Stockholm geol. foren. forh., 1891, 300.

Ilmenite is sometimes prefixed to those rocks which contain enough of the mineral to receive attention as ores: thus ilmenite-gabbro, ilmenite-norite, etc. See J. H. L. Vogt, Zeitschrift prakt. Geologie, I., 11, 1893.

Imandrite, a name suggested by W. Ramsay for a contact rock, believed to have been produced from graywacke by the neighboring nephelite-syenite of Umptek. The original feldspars are now largely silicified. (Cited by Rosenbusch, Mikr. Phys., 4th ed., II., 251.)

Inclusions, the term is applied to crystals and anhedra of one mineral involved in another; and to fragments of one rock inclosed in another, as when a volcanic flow picks up portions of its conduit.

Infusorial earth. See diatomaceous earth.

Intersertal, applied to those microscopic textures of igneous rocks which have in the interstices of well-developed minerals, residual masses of glass, *i. e.*, undifferentiated magma.

Intratelluric, a term applied to those processes that take place deep within the earth. For example, the large phenocrysts of a porphyry are usually of intratelluric cystallization. See p. 21.

Intrusive, the contrasted term with effusive, and applied to those rocks that have crystallized without reaching the surface. They therefore form dikes, laccoliths and batholiths. Plutonic is, to a certain extent, synonvmous. See p. 16.

Itabirite, a metamorphic rock, first described from Brazil, of schistose structure and composed essentially of quartz grains and scales of specular hematite. Some muscovite is also present. It is a close relative of itacolumite. It was named from Itabira, a place in Brazil. When it crumbles to powder it is called jacotinga. Heusser and Claraz, Zeit. d. d. geol. Gesellsch., XI., 448, 1859.

Itacolumite, or flexible sandstone, is a peculiar quartz schist first de-

scribed from Brazil, but since found in North Carolina and elsewhere. It is composed of quartz grains, to whose interlocking it is supposed to owe its flexibility; of muscovite, talc and a few other minerals, and has been regarded as the mother rock of the Brazilian diamonds. See p. 144.

J

Jacupirangite, a name derived from Jacupiranga, Prov. Saõ Paulo, Brazil, and applied by O. A. Derby to a group of igneous rocks, consisting sometimes of pure magnetite; again of magnetite with accessory pyroxene; or of pyroxene with accessory magnetite; or of pyroxene and nephelite and biotite and olivine in greater or less quantity. Amer. Jour. Sci., April, 1891, 314.

Jasper, red chalcedony, abundant enough on Lake Superior and elsewhere to be a rock.

Jasperoid, resembling jasper.

Jaspilite, a name originally proposed by Wadsworth for all the acid eruptive rocks, whose chemical and physical condition carries them above the rhyolites, but now used more or less loosely around Lake Superior for the jasper associated with the local iron ores.

Josefite, a name given by Szadeczky, to a peridotite occurring in dikes at Assuan, Egypt. Fold. Kozl., XXIX., 210, 1899. There seems to be no good reason for the new name. Cf. Tsch. Mitth., XIX., 169.

K

Kakirite, a name derived from Lake Kakir in Swedish Lapland and given by F. Svenonius, to extremely sheared and crushed rocks which are found in Lapland along thrust faults. The rocks are so badly crushed and altered that their original character cannot be deciphered. (See Eleventh Internat. Geol. Congress Guide-book I., No. 6, p. 26, 1910.)

Kaolinite, the hydrated silicate of alumina, Al_2O_3, $2SiO_2$, $2H_2O$, that is the base of clays and that gives them plasticity. When kaolinite is mingled with varying amounts of comminuted quartz, and yields a pure white clay, the mixture is kaolin. See p. 101.

Katamorphic. See Anamorphic.

Katzenbuckelite, a name suggested by A. Osann for the famous nephelite-porphyry or biotite-tinguaite porphyry of Katzenbuckel, Baden. Phenocrysts of nephelite, biotite, olivine, noselite and magnetite are set in a coarser or finer groundmass of nephelite, biotite and sometimes ægirite and amphibole. (Rosenbusch, Mikros. Phys., 4th ed., II., 632.) The rock is almost the same thing as the nephelite-porphyry or sussexite (which see) of Beemerville, N. J.

Kedabekite, a name given by E. von Federow to a dike rock from the Kedabek mines, government of Elizabethpol, Transcaucasia. The rock is finely granular, dark gray in color and consists of basic. plagioclase, lime-iron, garnet and a pleochroic pyroxene called violaite. Review in Amer. Jour. Sci., Sept., 1901, 247.

Kelyphite-rim, a name applied by Schrauf to rims of pyroxene, hornblende and spinel that sometimes surround the garnets of peridotites. It is used in the microscopic description of rocks.

Kentallenite, a name based on the Kentallen quarry in Argyllshire, Scotland, and given by Hill and Kynaston, to a basic member of the monzonite family, which contains chiefly, augite and olivine, and less abundantly, biotite, orthoclase, and plagioclase, the last two in somewhat variable relations. The rocks are very high in magnesia. Quar. Jour. Geol. Soc., LVI., 537, 1900. Cf. shonkinite.

Kenyte, a name given by J. W. Gregory to "liparitic representatives of an olivine-bearing nepheline syenite, consisting of anorthoclase phenocrysts and a glassy or hyalopilitic groundmass, which varies in color from grayish green to a deep sepia brown. Ægyrine, if present, occurs in small granules; ænigmatite and quartz are absent." The rocks occur as surface flows on Mt. Kenya in East Africa and are practically phonolites with a glassy groundmass. Quar. Jour. Geol. Soc., LVI., 211, 1900. Amer. Jour. Sci., Sept., 1901, 247.

Keratophyre, a rock intermediate between porphyries and porphyrites, and differing from either in having as the principal feldspar, anorthoclase instead of either orthoclase or the soda-lime feldspars. Keratophyre applies to pretertiary rocks, whereas pantellerite is used for the same aggregate of more recent geological date. The name was given in 1874 by Gümbel to certain Bavarian felsitic and porphyritic rocks, that resembled hornfels, hence the name from the Greek for horn. Its significance has since been restricted.

Kern, the German word for core, introduced in a special sense into petrology by H. Rosenbusch, in the development of the Kern-theorie. (Tsch. Mitth., 11: 144, 1889.) The author tabulates a series of rock analyses, representing the various types of igneous rocks. These are recast to molecular proportions, and then to atomic proportions, alike of silicon and the metallic elements. Combinations of these are next developed which are called Kerns, and which are believed to be characteristic of the different igneous types, such as granites, syenites, nephelite syenites, etc.

Kersantite, a very old name of somewhat varying application, but formerly used for rocks that are intermediate between diorites or their

corresponding porphyrites and gabbros or diabases. Mica-diabase was used as a synonym. Rosenbusch, in carrying out the separation of the dike rocks from the effusive and intrusive grand divisions, has sought to restrict the name to those dike rocks with plagioclase that have prevailing dark silicates of which the chief is biotite. Kersanton is practically a synonym. Both names are derived from a town in Brittany.

Kies, a general term for the sulphide ores, now adopted into English from the original German.

Kieselguhr, German name for diatomaceous earth, and more or less current in English.

Killas, Cornish miner's term for the slates or schists that form the country rock of the Cornish tin veins.

Kimberlite, a name given by H. Carville Lewis to the peridotite, that in large part forms the diamantiferous neck at the Kimberly mines, of South Africa. (Geol. Magazine, 1887, 22.) The rock is more porphyritic than typical peridotite.

Kinzigite, a metamorphic rock consisting of biotite, garnet and oligoclase. It was named in 1860 by Fischer, from the Kinzig Valley, in the Black Forest. Neues Jahrb., 1860, 796.

Knotty, a descriptive term for those slates or schists, which are so altered by contact metamorphism as to have new minerals developed in them, giving them a spotted or knotty appearance. See p. 127.

Kodurite, a name derived from the Kodur manganese mine near Vizagapatam, in the northeastern portion of the Madras Presidency, India. It was given by L. L. Fermor to a rock consisting of potash feldspar, manganese garnet, and apatite. It is usually of granitoid texture, with medium coarseness of grain, but it may be pegmatitic. (Geol. Survey of India, XXXV.)

Koellite, a name suggested by W. C. Brögger for a basic dike-rock, consisting of olivine, lepidomelane, barkevicite, apatite, magnetite, anorthoclase and nephelite. (H. Rosenbusch, Mikros. Phys., 4th ed., II., 705.)

Koswite, a name derived from Mt. Koswimsky in the Urals and given by Duparc and Pearce, to a melanocratic, granular rock composed of varieties of pyroxene, olivine, hornblende, chromiferous spinels and magnetite; the last-named constituting a matrix or cement for the others. Mem. Soc. Phys. et d'Hist. nat. de Genève, XXXIV., 218. Amer. Jour. Sci., Jan., 1903, 84.

Krablite, ejected blocks from the volcano of Krafla, in Iceland, which were regarded many years ago by Forchhammer, under the name

baulite, as a feldspar, of percentage in silica far beyond that of albite. (Jour. f. prakt. Chemie, 1843, 390; Jahresber. über die Fortschrit. Chemie u. Mineralogie, 1844, 262.) It was soon shown by the micro. scope to be an aggregate.

Krageröite, a gabbroic rock, consisting of plagioclase and rutile and occurring at Kragerö, Norway. (H. Rosenbusch, Mikr. Phys., 4th ed., II., 354.) Compare nelsonite.

Krassyk, a local name for a decomposed ferruginous schist—in the Beresov gold-mining district of the Urals. Archiv für practische Geologie, II., 537.

Kugel, the German word for ball or sphere and often prefixed to those igneous rocks that show a spheroidal development, such as corsite, orbicular granite, etc.

Kulaite, a name derived from the Kula basin in Lydia, Asia Minor, proposed by H. S. Washington, for those rare basalts (there abundant) in which hornblende surpasses augite in amount. "The Volcanoes of the Kula Basin." Privately printed. New York, 1894, Amer. Jour. Sci., Feb., 1894, p. 115.

Kullaite, a name derived from the Swedish locality Kullen, and applied by A. Hennig to a dike-rock which is regarded as an intermediate type between the diabases and the granites. In a feldspathic groundmass of ophitic (diabasic?) texture, are red phenocrysts of plagioclase and microcline. The groundmass has rods of oligoclase-andesine with augite, orthoclase and titaniferous magnetite. See Review in Neues Jahrbuch, 1901, II., 59.

Kuskite, a name derived from the Kuskokwim river, Alaska, and applied by J. E. Spurr to certain porphyritic dikes, which cut Cretaceous shales, and which have phenocrysts of quartz, scapolite, and probably basic plagioclase (the last now represented by alteration products), in a groundmass of quartz, orthoclase and muscovite. Compare yentnite, Amer. Jour. Sci., Oct., 1900, 311 and 315.

Kyschtymite, a name derived from the Kyschtym mining district of the Urafs, and given by J. Morozewicz to a rock consisting chiefly of anorthite and corundum, with which are associated biotite, spinel, zircon, apatite and, as secondary minerals, muscovite, chlorite, kaolinite and chromite, Tsch. Mitth., XVIII., 212, 1898.

L

Labile, the condition which is reached by a cooling solution when crystallization spontaneously takes place. It is in a measure contrasted with metastable. (See Iddings, Igneous Rocks, 1: 160, 1910.)

Labradorite, the name of the feldspar is prefixed to many rock names. Labradorite rock was formerly much used for anorthosite, which see.

Laccolite, a name based on the Greek word for cistern and suggested by G. K. Gilbert for those intrusions of igneous rock that spread out laterally between sedimentary beds like a huge lens, and that never reach the surface unless exposed by erosion. See p. 15; also Geology of the Henry Mountains, Utah, p. 19.

Lamprophyre, a general term, now used in a somewhat wider sense than as originally proposed by Gümbel, who suggested it. Rosenbusch, in the Massigen Gesteine, gave it its present significance. Lamprophyres are dike rocks of porphyritic texture, whose predominant phenocrysts are the dark silicates, augite, hornblende or biotite. They are practically basic dikes. The word means a shining rock, and was first applied in 1874 to small dikes in the Fichtelgebirge that were rich in biotite. In a somewhat modified sense it has recently been employed by L. V. Pirsson, as single term for the basic "complementary rocks" (see Complementary Rocks), and as the antithseis of oxyphyre, which applies to the acidic complementary rocks of an eruptive area.

Lapilli, volcanic dust and small ejectments, the results of explosive eruptions.

Lassenite, Wadsworth's name for unaltered, glassy trachytes. Rept. State Geol. Mich., 1891–92, p. 97. The name is derived from Lassen's Peak, Cal.

Laterite, a name derived from the Latin word for brick earth, and applied many years ago to the red, residual soils or surface products, that have originated in situ from the atmospheric weathering of rocks. They are especially characteristic of the tropics. Though first applied to altered, basaltic rocks in India, laterite has had in later years a general application without regard to the character of the original rock. Compare saprolite. See pp. 154, 155.

Latite, a name suggested by F. L. Ransome, for the rocks that are intermediate among the trachytes, andesites and basalts. Latite is meant to be a broad family name and to include the effusive representatives of the plutonic monzonites. Plagioclase and orthoclase are both present; augite, hornblende, biotite and olivine vary in relative amounts. The textures may be glassy, felsitic or porphyritic. The name is derived from the Italian province of Latium but was suggested by studies on Table Mtn., Tuolumne Co., Calif., Bull. 89, U. S. Geol. Survey. Compare trachydolerite, ciminite, vulsinite, monzonite.

Laurdalite, a name given by Brögger to a coarsely crystalline variety of nephelite-syenite, that is abnormal in having for its feldspar natron-

orthoclase, rarely natron-microcline, instead of the normal potash orthoclase. The dark silicates are biotite, diallage and olivine. Zeitsch. f. Kryst., XVI., 28, 1890.

Laurvikite, a name applied by Brögger to a Norwegian variety of augite-syenite that contains natron-orthoclase as its chief feldspar and most abundant mineral. The other components are rare plagioclase, pyroxene, biotite, barkevicite or arfvedsonite, olivine and magnetite: Besides microscopic accessories, nephelite is occasionally met. Zeitsch. f. Kryst., XVI., 29, 1890. Compare pulaskite.

Lava, a general name for the molten outpourings of volcanoes.

Laxite, Wadsworth's name for the fragmental or mechanical rocks, especially when unconsolidated. Rept. of State Geol. of Mich., 1891–92, p. 98.

Lenneporphyry, consolidated tuffs in the Devonian of Westphalia and having the composition of quartz-keratophyres. The name is derived from the Lenne, a stream along which they occur.

Lentils, a short name for lenticular beds in a stratified series.

Leopardite, a siliceous rock from North Carolina, spotted with stains of manganese oxide. It is usually considered to be a quartz-porphyry.

Leopard rock, a local name in Canada, applied to pegmatitic rocks which are associated with the apatite veins of Ontario and Quebec. See C. H. Gordon, Bulletin Geolog. Society of America, VII., 122.

Leptinite or **Leptynite,** the French synonym of granulite as used among the Germans. See granulites.

Leptite, a term now widely used by the students of the Precambrian formations in Sweden for all the very finely schistose and close-grained rocks, such as have been previously called hälleflintas, eurites, porphyroids, fine phyllites, etc. (A. Högbom, Bull. Geol. Inst. Univ. of Upsala, 10: 42, 1910.)

Leptomorphic, a term suggested by Gümbel for crystallized substances which lack definite crystalline borders, as the nephelite in many groundmasses. Fichtelgebirge, 1879, 240.

Lestiwarite, a name proposed by Rosenbusch for the aplitic dike-rocks that accompany nephelite-syenites in Norway and Finland. They are chiefly or almost entirely alkali feldspar, with very subordinate pyroxene or amphibole. They have been previously called syenite-aplites by W. C. Brögger. Lestiwarite is derived from the Finnish locality Lestiware. Massige Gesteine, II., 464. Das Ganggefolge des Laurdalits, 207.

Leucite, the name of the mineral is prefixed to the names of many rocks which contain it, as, leucite-absarokite, leucite-syenite, etc.

Leucite-basalt, basaltic rocks with olivine, in which leucite replaces plagioclase. See p. 72.

Leucite-basanite, basaltic rocks that contain both leucite and plagioclase. As contrasted with leucite-tephrites, they contain olivine. See p. 72.

Leucitite, basaltic rocks without olivine in which leucite replaces plagioclase. Compare leucite-basalt.

Leucitophyre, a name formerly used as a general one for the leucite rocks, but now by common consent restricted to those phonolites that contain both leucite and nephelite.

Leucite-tephrite, basaltic rocks without olivine, that contain both plagioclase and leucite. Compare leucite-basanite.

Leucocratic, a descriptive term, suggested by W. C. Brögger for those eruptive rocks in which the light-colored minerals, *i. e.*, the feldspars, feldspathoids and quartz, are in excess over the dark-colored (ferromagnesian) minerals. Leucocratic is derived from two Greek words meaning "white prevails." The antithetical term is melanocratic.

Leucophyre, originally applied by Gümbel in 1874 to light-colored diabases whose feldspar was altered to saussurite and whose augite had largely changed to chlorite. Rosenbusch restricts it to diabases poor in plagioclase. The name means a light-colored or white porphyritic rock, and has little claim to consideration either in etymology or application.

Lherzolite, a variety of peridotite, first discovered in the Pyrenees, and containing olivine, diopside and an orthorhombic pyroxene. Much picotite is also present. It was named from Lake Lherz, by de la Méthérie, Theorié de la Terre, II., 281.

Liebenerite-porphyry, nephelite-porphyry whose nephelite phenocrysts are altered to muscovite. Its original locality is near Predazzo, in the Tyrol. Compare gieseckite-porphyry.

Limburgite, porphyritic basaltic rocks consisting of olivine and augite in a glassy groundmass. They lack feldspars. See p. 73. The name is derived from Limburg, a locality on the Kaiserstuhl, a basaltic mountain in Baden. It was suggested by Rosenbusch in 1872, and at the same time Boricky described similar rocks from Bohemia as magma-basalt.

Limestone, the general name for rocks composed essentially of calcium carbonate. See p. 105.

Limurite, a name for a rock consisting of axinite, pyroxene, amphibole, quartz, titanite, calcite, pyrite and pyrrhotite, which occurs on

the contact of granite and limestone, although formerly thought to be a member of the crystalline schists. A. Lacroix, Comptes rendus, CXIV., 955, 1892.

Lindoite, Brögger's name for certain dike rocks, in the region of Kristiania. They have trachytic texture; are seldom and then but slightly porphyritic; are medium to coarsely crystalline in the larger dikes; possess light colors and often lack dark-colored minerals. When such are recognizable they are pyrite and chlorite. Ferriferous carbonates are present. Traces of ægirite and of a dark, alkaline hornblende may be occasionally detected. (Die Eruptivgesteine des Kristianiagebietes, I., 131, 1894.)

Linophyric, having the phenocrysts of a porphyritic rock in lines. (Jour. Geol., 14: 703, 1906.)

Liparite, a synonym of rhyolite, and largely used for the latter among Europeans, though rhyolite is chiefly current in America and England. The name is derived from the Lipari Islands, off the coast of Italy, where the rocks are abundant. It was proposed by Justus Roth in 1861. Gesteins-analysen, p. xxxiv.

Listvenite, a local name for a rock in the gold-mining district of Beresov, in the Urals. It is regarded as a contact zone produced from dolomite, and is a coarsely crystalline aggregate of magnesite, talc, quartz and limonite, pseudomorphic after pyrite. Archiv für practische Geologie, II., 437.

Litchfieldite, a name proposed by W. S. Bayley for the variety of nephelite-syenite, occurring near Litchfield, Maine, in loose boulders whose chief feldspar is albite and which differ therein from normal nephelite-syenite. Bull. Geol. Soc. Amer., III., 243.

Lithical, a term proposed by L. Fletcher for the finer, textural characters of rocks, *i. e.*, those for which texture, as distinguished from structure, is employed above. See p. 16. Lithical, from the Greek for stone, is contrasted with petrical, from the Greek for rock. Introduction to the Study of Rocks; British Museum Handbooks, 1895.

Lithionite-granite, a name proposed by Rosenbusch for granites with lithia mica or lithionite.

Lithographic limestone, an exceptionally homogeneous and fine-grained limestone, suitable for lithography.

Lithoidal, a descriptive term applied to those groundmasses, especially of rhyolites, that are excessively finely crystalline, like porcelain, as distinguished from glassy varieties. The English equivalent, stony, is also used.

Lithology, that branch of geology which makes rocks a special object

of study. Practically synonymous with petrology: the former being derived from the Greek for stone; the latter from the Greek for rock. Lithology was current 30–50 years ago and has been to a large degree displaced by petrology or petrography since 1890.

Lithophysæ, literally "stone bubbles," a name applied to those cellular cavities in acidic lavas, obsidian, rhyolite, etc., that have concentric walls, and that are caused by a special development of mineralizers at that particular point. They were usually hemispherical in shape and on the walls may have various well crystallized minerals. See pp. 26, 27.

Lithosphere, the outer stony shell of the earth. See barysphere.

Local metamorphism, *i. e.*, contact metamorphism. See p. 122.

Loess, fine surface soils chiefly formed of wind-blown dust. See p. 99. The name is a German word, akin to loose, and appears to have been first applied geologically in the Rhine valley.

Luciite, Chelius' name from the Luciberg in Hesse, for finely crystalline, diorite dikes, whose minerals are xenomorphic. Notizblatt Verein. f. Erdkunde, Darmstadt, 1892, 1.

Luijaurite, a name proposed by Brögger for a nephelite-syenite, rich in ægirite and eudialyte. Zeitsch. f. Kryst., XVI., 204. The name is from a Lapland locality, where the rock was discovered by Ramsay.

Lustre-mottlings, a name applied by Pumpelly to certain augitic rocks, which have a shimmering lustre because the shining cleavage faces of the augite crystals are mottled by small inclusions. Proc. Amer. Acad., XIII., 260, 1878. Compare Poicilitic and Schiller.

Luxullianite, a tourmaline granite from Luxullian, in Cornwall, that is a product of contact metamorphism. See p. 35.

Lutite, a general name, suggested by A. W. Grabau for finely fragmental sediments, such as shales, clays, argillaceous limestones, etc. Prefixes define the kind of sediment, such as silicolutite, calcilutite and the like. (Bull. Geol. Soc. Amer., 14: 348–352.) The adjective is lutaceous.

Lydite. See Basanite.

M

Macroscopic, a word formerly current as a synonym of megascopic, *i. e.*, recognizable by the naked eye. It is etymologically less correct as an antithesis of microscopic than is megascopic, for "macro" is from the Greek for broad, whereas "mega" means large. Nevertheless, it preceded megascopic in general use and is still current.

Madupite, a name given by Whitman Cross to a peculiar group of rocks which are illustrated by one forming Pilot Knob, a mesa about 6

miles northwest of Rock Springs, Wyo. Cross defines Madupite "as consisting essentially of diopside and a magnesia-potash mica with leucite in decidedly subordinate amount. Its magma is low in silica, alumina and iron, rich in potash, and contains so much lime and magnesia that silicates of these bases are the principal constituents, yet controlled in their development by the strong potash element." The Pilot Knob case is a vitrophyric representative of the type, so defined. Amer. Jour. Sci., Aug., 1897, 139.

Mænaite, a name derived from Lake Mæna, near Gran, Norway, and given by W. C. Brögger to an intrusive trachytic rock, regarded as a differentiation product of a gabbro-magma. Mænite is a bostonite relatively rich in lime and poor in potash. Erupt. Gest. Krist., III., 207, 1899.

Magma is now generally employed for the molten masses of igneous rock before they have crystallized. An original, parent magma may break up into several derived ones, a process called magmatic differentiation. See p. 20. Magma is also used in the sense of basis as earlier defined, but this use is unfortunate.

Magma-basalt, a synonym of limburgite, which was proposed by Boricky, in 1872, at about the same time that Rosenbusch suggested limburgite. Some authorities give the former the preference.

Magnetite, the name of the mineral is prefixed to the names of many rocks in which it is prominent. It almost furnishes a rock itself, at times.

Magnetite-olivinite, a name coined by A. Sjögren in 1876 for the igneous iron-ore at Taberg, in Sweden. The rock is an aggregate of magnetite and olivine, with a few shreds of biotite. The rock is practically a peridotite, greatly enriched with titaniferous magnetite. On the borders of the intrusion it shades into gabbro. Geol. Fören. in Stockholm, Forhandl., III., 42. Compare Cumberlandite.

Magnetite-spinellite, an eruptive iron ore occurring at Routivara, Sweden, and consisting of magnetite (in part titaniferous), spinel, and smaller amounts of olivine, pyroxene, apatite and pyrrhotite. The ore contains about 14 per cent. titanic oxide. W. Petersson, Geol. Fören. Forh., XV., 49, 1893.

Magnophyric, coarsely porphyritic phenocrysts greater than 5 mm. (Jour. Geol., 14: 702, 1906.) If spelt magniphyric, the texture is coarse only in a microscopic sense; phenocrysts .2–.04 mm.

Malchite, a variety of diorite dikes which have, in a groundmass of quartz, feldspar and hornblende, phenocrysts of plagioclase, hornblende and biotite. The name was given by A. Osann, and is derived from Malchen, another name for Mt. Melibocus, in Hesse.

Malignite, a name proposed by Lawson for a group of rocks on the Maligne river, Rainy Lake district, province of Ontario. They are described as "basic, holocrystalline, plutonic rocks, rich in alkalies and lime." Iron is present in moderate amounts, almost entirely combined in the silicates. Iron and magnesia are more abundant than is usual in the alkali-rich plutonic rocks. The chief minerals are orthoclase, often microscopically intergrown with an acid plagioclase; ægirite-augite, which may predominate with but a moderate admixture of biotite, or may be subordinate and intergrown with preponderant soda amphibole, biotite, being present as before. There are three types of malignites, one of which has much melanite and another much nephelite. Bull. Dept. Geol. Univ. Calif., I., 340, 1896.

Manganolite, Wadsworth's name for rocks composed of manganese minerals, such as wad, psilomelane, etc. Rept. State Geol. Mich., 1891–92, p. 93.

Mangerite, a name based upon Manger, a Norwegian locality, by C. F. Kolderup and applied to granitoid rocks consisting essentially of microperthite and augite. By dynamic metamorphism the augite may pass into hornblende and biotite. Gneissoid structures are also induced. Quartz-mangerites represent acid facies. The rocks are associates of the anorthosites of Norway. (Die Labradorfelsen des westlichen Norwegens, Bergens Museums Aarbog, 1903, 102.) The same rocks are abundant in the Adirondacks where they are commonly called syenites.

Marble, in lithology, a metamorphosed and recrystallized limestone. In the trade the name is applied to any limestone that will take a polish.

Marekanite, a rhyolitic perlite from the banks of the Marekana river, near Ochotsk, Siberia. At times a very clear glass, it is found in balls and cores of large perlitic masses and may even be under strain like Prince Rupert's drops. See Zirkel's Petrographie, II., 299.

Mariupolite, a name derived from Mariupol, a locality on the sea of Azov, and applied by J. Morozewicz to a variety of nephelite-syenite, so rich in soda and poor in potash that orthoclase practically fails. An estimate of the percentages of the component minerals gave, albite, 73, nephelite, 14, ægirite, 7.6, lepidomelane, 4, zircon, 1.6. The texture varies from coarsely crystalline to porphyritic and to compact, according to the occurrence of the rock in large masses or in dikes. Tsch. Mitth., XXI., 241, 1902. Compare litchfieldite.

Markfieldite, a hypabyssal igneous rock, intermediate between granophyre and dolerite; *i. e.*, a dioritic granophyre. (Hatch, Textbook of Petrology, 5th ed., 219, 1909.)

Marl, a calcareous clay, or intimate mixture of clay and particles of calcite or dolomite, usually fragments of shells. Marl in America is chiefly applied to incoherent sands, but abroad compact, impure limestones are also called marls.

Marmorosis, the general name for the process of crystallization of limestones to marble, whether by contact or regional metamorphism. It was coined by Geikie from the Latin for marble.

Marscoite, an intermediate contact rock, produced by the action of granite during deep-seated stages, upon included fragments of gabbro. Various new minerals result and old ones have new physical properties. (A. Harker, Tertiary Igneous Rocks of Skye, Mem. Geol. Survey, United Kingdom, 1904, 175, 192.)

Massif, a single mountainous mass, which may be considered a unit.

Massive, the antithesis of stratified, and therefore, often used as a synonym of igneous or eruptive rocks as contrasted with the bedded sedimentary and laminated metamorphic varieties.

Mediophyric, moderately porphyritic; phenocrysts 1–5 mm. If spelled mediiphyric the term is used only in a microscopic sense; phenocrysts, .04–.008 mm. Jour. of Geol., 14: 702, 1906.

Megascopic, a descriptive term meaning large enough to be distinguished with the naked eye; the antithesis of microscopic. See macroscopic. Used also to describe methods of observation without the microscope or with the eye alone.

Megaphenocrysts, large phenocrysts. (Jour. Geol., 14: 702, 1906.) The texture is megaphyric.

Melanocratic, a name applied by W. C. Brögger to those eruptive rocks, in which the dark or ferromagnesium minerals are in excess over the light ones. The antithetical term is leucocratic. Melanocratic is derived from two Greek words meaning the "black prevails."

Melaphyre, a rock name first introduced by Brongniart in 1813, practically for porphyritic rocks with a dark groundmass and with feldspar phenocrysts. After having had various meanings for many years, by common consent, it is now generally used as suggested by Rosenbusch for pretertiary olivine-basalts, that is, for porphyritic equivalents of olivine-diabase.

Melilite, the name of the mineral is sometimes prefixed to the names of rocks containing it, as melilite-monchiquite.

Melilite-basalt, a rare basaltic rock whose feldspathoid is melilite. It was first identified by Stelzner in 1882. The rock is excessively basic. Alnoite is the same rock in dikes.

Mesostasis, a synonym of basis suggested by Gümbel.

Meta, the Greek preposition for after, used as a prefix in the names of various rocks which are derived from preëxisting rocks; or in the names of various geologic processes involving change.

Metabolite, Wadsworth's name for altered, glassy trachytes, of which lassenite is the unaltered form. Rept. State Geol. Mich., 1891–92, p. 97.

Metachemical metamorphism, Dana's term to describe that variety of metamorphism that involves a chemical change in the rocks affected. Amer. Jour. Sci., July, 1886, p. 69.

Metacrystal, see under Brotocrystal.

Metadiabase, a shortened form of metamorphic diabase, suggested by Dana for certain rocks simulating diabase, but supposed to have been produced by the metamorphism of sediments. Amer. Jour. Sci., Feb., 1876, 121. Compare Pseudo-diabase.

Metadiorite, dioritic rocks produced as just described under metadiabase. Compare Pseudo-diorite.

Metagabbro, a metamorphosed gabbro: necessarily therefore a gabbro more or less completely changed to an amphibolite. (Amer. Jour. Sci., Feb., 1904, 145.)

Metarhyolite, a name applied to rocks which were originally rhyolite, but which are now altered in mineralogy, by recrystallization, so as to develop microperthite, or products of devitrification, or some other change from their original condition. Bull U. S. Geol. Survey, No. 150, p. 164. Aporhyolite being generally accepted, metarhyolite would appear to be superfluous.

Metamorphism, a collective term for the process by which rocks undergo alteration of all sorts. It is more fully set forth on page 122.

Metasomatic, *i. e.*, a change of substance; it is used to describe the replacement of one or more of the minerals of a rock by others. The form of the originals is not at all preserved as in pseudomorphs, nor does the chemical composition remain the same while the form alters as in paramorphs, but both customarily change. The term is especially used in connection with the origin of ore deposits. The corresponding noun is metasomatosis, but replacement is a good English equivalent.

Metastable, the condition which is reached by a cooling solution, when, being supersaturated, crystallization is instantly induced by the introduction of a solid, though perhaps very minute. (See Iddings, Igneous Rocks, 1: 159, 1910.)

Metaxite, a name of Hauy's for micaceous sandstone.

Mexican Onyx, banded, stalagmitic marble, originally from Mexico and used as an ornamental stone. The name is now generally employed as a trade designation.

Mezo or **Meso** is sometimes prefixed to the names of igneous rocks of Mesozoic age.

Miarolitic, a descriptive term applied to those granitoid rocks that have small cavities, into which well-terminated crystals project. See p. 17.

Miascite, a name coined from Miask, a locality in the Urals where a nephelite-syenite occurs whose dark silicate is biotite. Used also as a general name for biotitic nephelite-syenites. See p. 52.

Mica, the name of the mineral is often prefixed to the name of the rock containing it, as, mica-basalt, mica-tinguaite, mica-trachyte, etc.

Mica-peridotite, a name applied by J. S. Diller to a peculiar peridotite, occurring as a dike in Crittenden County, Ky., and consisting chiefly of altered olivine and biotite. Amer. Jour. Sci., Oct., 1892, 288. See Analysis 8, p. 81.

Mica-schist, finely laminated, metamorphic rocks, consisting of quartz, mica, feldspar and several minor minerals. See p. 137.

Mica-syenite, syenite whose dark silicate is biotite.

Mica-trap, an English field name for dark, dike rocks rich in mica.

Microdiabase, a name given by Lossen to aphanitic diabases.

Microdiorite, a name originally given by Lepsius to a fine-grained diorite-porphyry, Das westliche Süd-Tirol, 1878.

Micro-felsite, a name used in microscopic work for those varieties of groundmass that do not affect polarized light, but that are not true glasses because they have a fibrous, a granular or some such texture. The textures are no doubt in many cases the results of the devitrification of a glassy base.

Micro-granite, a name used in microscopic work for those groundmasses of porphyritic rocks, that consist of small quartz and feldspar crystals with granitoid texture on a small scale, *i. e.*, with components of about the same size and usually without crystallographic boundaries. See granophyric.

Micro-granulite, the French equivalent of granophyric, as earlier explained.

Micro-crystalline, granular rocks, whose components are recognizable, but are so small as to require the microscope for their identification.

Microlites, generally used for microscopic, but still identifiable minerals.

Micropegmatite, *i. e.*, microscopic pegmatite, a term applied to those groundmasses of porphyritic rocks whose microscopic quartz and feldspars mutually penetrate each other. The several parts of the same crystal, though isolated, extinguish together. See granophyric.

Microperthite, *i. e.*, microscopic perthite, a term applied to that variety of orthoclase which is thickly set with flat spindles of albite. It is very common in gneisses. Compare granophyric.

Microphenocrysts, phenocrysts only observed with the microscope. The texture is microphyric. (Jour. Geol., 14: 702, 1906.)

Micropoikilitic, a textural term suggested by G. H. Williams to describe those minerals that are speckled with microscopic inclusions of other minerals, having no definite relations to each other or to their host. Jour. of Geology, I., 176, 1893. Poikilitic is often spelled poicilitic or poecilitic.

Mijakite, an andesite from the Japanese island of Mijakeshima from which the name is derived. It is porphyritic with phenocrysts of bytownite, augite, hypersthene and biotite. In the groundmass are brown pyroxene, feldspar and basis. Largely on the results of the chemical analysis, the brown pyroxene is believed to be a manganese-bearing, triclinic variety related to babingtonite, hence the new name for the rock. J. Petersen, Jb. Hamburg Welt Ausstellung, VIII., 50, 1891.

Millstone-grit, an old English name for the conglomeratic sandstone at the base of the Carboniferous Coal Measures. It is more or less current in this country as a synonym of the Great, Pottsville or Seral conglomerate.

Mimesite, an obsolete synonym of dolerite.

Mimophyre, a name suggested by Elie de Beaumont in 1841 for metamorphosed, argillaceous rocks in which feldspars had developed, so that they resembled porphyries. Volcanic tufts are a frequent original, but graywackes and arkoses have also yielded them. Compare Porphyroid.

Mineralizers, the dissolved vapors in an igneous magma, such as steam, hydrofluoric acid, boracic acid and others, that exert a powerful influence in the development of some minerals and textures. See p. 18. The word is also technically used in some definitions of ore. Thus it is said that an ore is a compound of a metal, and a mineralizer which disguises its metallic properties; such as copper with sulphur, iron with oxygen, etc.

Minette, a variety of mica-syenite, usually dark and fine-grained, occurring in dikes. See p. 44, Anal. 6.

Minophyric, minutely porphyritic, phenocrysts 1–0.2 mm. Miniphyric is used in a microscopic sense, phenocrysts, less than .008 mm. (Jour. Geol., 14: 702, 1906.)

Missourite, a granitoid rock consisting of leucite, biotite, augite, olivine, iron ores and apatite, and corresponding to the effusive leucite-

basalts. It was discovered in the Highwood Mountains, Mont., by Weed and Pirsson, and named by them from the Missouri River, "the most prominent and best known geographical object in the region."

Moldauite, a very pure glass, from the valley of the Moldau river, Bohemia, and believed to be meteoritic in origin. See Bouteillenstein.

Monchiquite, a name suggested by Hunter and Rosenbusch from the Monchique Mountains of Portugal, for basaltic dikes corresponding in mineralogy and texture to limburgite. They often accompany nephelite-syenite. Tsch. Mitt., XI., 445, 1890. In modification of the original view that the monchiquites have a glassy groundmass, L. V. Pirsson has urged with much reason and with the additional evidence of chemical analysis, that the supposed glass is analcite. The presence of so much glass in so basic a rock is improbable. Journal of Geology, IV., 679.

Mondhaldeite, a name derived from a locality on the Kaiserstuhl, Baden, and applied by A. Osann to a group of dike rocks having the mineralogy of the hornblende-pyroxene andesites. Chemically they are andesites of about 60 per cent. in silica, and with almost as much potash as soda. Tscherm. Mitth., XXI., 416, 1902.

Monmouthite, a basic, granitoid rock whose essential minerals are nephelite and hornblende, and whose more frequent accessories are plagioclase, cancrinite, and calcite, with sodalite, apatite, sphene, biotite, pyrite and iron ores in extremely small amount. The monmouthite appears as bands produced by magmatic differentiation in an albitic nephelite syenite (litchfieldite) along its contact with limestone. On analysis the chief constituents of monmouthite were the following: SiO_2 39.74, Al_2O_3 30.59, FeO 2.19, CaO 5.75, K_2O 3.88, Na_2O 13.25, CO_2 2.17, H_2O 1.00; all the rest 1.29, no one being over .60, total 99.86. The name was given by F. D. Adams and is derived from the township of Monmouth, Ontario. (Amer. Jour. Sci., April, 1904, 269.)

Monzonite has usually been considered as a variety of augite-syenite that displayed, however, considerable mineralogical variety. Brögger has recently used the name for a transitional and intermediate group of granitoid rocks between the granite-syenite series (*i. e.*, the alkali-feldspar series) and the diorites (*i. e.*, the lime-soda feldspar series). The monzonites have both alkali-feldspar (or orthoclase) and lime-soda feldspar (or plagioclase) in approximately equal amounts, or at least both richly. (Die Eruptivgesteine des Kristianiagebietes, II., 21, 1895.) With the meaning proposed by Brögger the name has been much used by the U. S. Geol. Survey in monographs on western mining districts. If some, but not much quartz is present the rock becomes quartz-mon-

zonite, as in the basic granite at Butte, Mont. Increasing quartz leads to grano-diorite.

Mortar-structure, a term suggested by Törnebohm to describe those granites, gneises or other rocks that have been dynamically crushed, so that large nuclei of their original minerals are set in crushed and comminuted borders of the same, like stones in a wall.

Mugearite, the hypabyssal equivalent of essexite. It consists of oligoclase, subordinate orthoclase, olivine, augite, apatite and iron ore. (Alfred Harker, Mem. Geol. Surv. of Great Britain, 1904, 265.)

Mulatto, a local name in Ireland for a Cretaceous green sand.

Muscovado, the Spanish word for brown sugar, used by Minnesota geologists for a rusty, brown, outcropping rock that resembles brown sugar. It has been applied to both gabbros and quartzites. 16th Ann. Rept. Minn. Geol. Surv.

Mylonite, a name suggested by the English geologist Lapworth for schists produced by dynamic metamorphism. Rept. of Brit. Assoc., 1885–86, p. 1025.

Myrmekite, graphic granite, the eutectic of quartz and feldspar, common in pegmatites.

N

Nadel-diorite, *i. e.*, needle-diorite, a German term for diorites with acicular hornblende.

Napoleonite, a synonym of corsite.

Natron-granite, granites abnormally high in soda, presumably from the presence of an orthoclase rich in soda, or of anorthoclase. They are also called soda-granites. Natron is likewise used as a prefix to minerals and rocks that are rich in soda, as natron-orthoclase, natron-syenite, etc.

Navite, Rosenbusch's name for pretertiary, porphyritic rocks, consisting of plagioclase, augite and olivine as phenocrysts, with a second generation of the same forming the holocrystalline groundmass. The name is from Nava, a locality in the Nahe Valley. Mass. Gest., 1887.

Necks, lava-filled conduits of extinct volcanoes, exposed by erosion.

Nelsonite, a name derived from Nelson Co. Virginia, and given by T. L. Watson to a rock consisting of rutile and apatite as essential minerals, with ilmenite, pyrite and quartz as accessories. It is mined as a source of titanium and is obviously related to the pegmatites. Compare Krageröite. (Mineral Resources of Virginia, 300, 1907.)

Neolite, a name used by Clarence King for an order of volcanic rocks, embracing the rhyolites and basalts, with which according to the

succession formulated by von Richthofen, eruptive activity terminates in any given area. Geol. Survey of the Fortieth Parallel, I., 689.

Nepheline, see Nephelite.

Nephelinite, basaltic rocks consisting of nephelite, augite and basis, but without olivine. See p. 72.

Nephelinitoid, Boricky's term, now used in microscopic work for nepheline-glass, or the glassy basis in nepheline rocks, whose easy gelatinization indicates its close relations with this mineral; unindividualized nephelite.

Nephelite, a later method of spelling nepheline and one consistent with approved mineralogical orthography.

Nephelite-basalt, an old, general name for basaltic rocks with nephelite, but now restricted to those that practically lack plagioclase, and that have nephelite, augite, olivine and basis. See p. 72.

Nephelite-basanite, basaltic rocks with plagioclase, nephelite, augite, olivine and basis. Compare nephelite-tephrite. See p. 72.

Nephelite syenite, *i. e.*, eleolite-syenite, a name to be preferred to the latter as there is no real need of the word eleolite. Granitoid rocks consisting of orthoclase, nephelite, and one or more of the following: hornblende, augite and biotite. The rocks result from magmas especially rich in alkalies, and possess great scientific interest on account of their richness in rare, associated minerals. See p. 51.

Nevadite, a name coined by von Richthofen from Nevada, for those rhyolites that approximate a granitoid texture, *i. e.*, with little groundmass. Mem. Calif. Acad. Sci., I., p. 54, 1867. See p. 24 and Hague and Iddings, Amer. Jour. Sci., June, 1884, 461.

Névé, a French synonym of firn.

Nonesite, porphyrites with orthorhombic pyroxene. The name was given by Lepsius. Das westliche Süd-Tyrol, Berlin, 1878.

Nordmarkite, Brögger's name for a variety of granitic rocks consisting of orthoclase, some oligoclase, more or less microperthite, quartz and somewhat subordinate biotite, pyroxene, hornblende and ægirite. Nordmarkites are high in silica and the alkalies. Zeitsch. f. Kryst., XVI., 54, 1890.

Norite, a rock of the gabbro family that consists of plagioclase and orthorhombic pyroxene, usually hypersthene. The name has had a variable history and was originally proposed in 1832 by Esmark for aggregates of feldspar and hornblende which were lacking or notably poor in diallage and hypersthene. But as many localities were cited which in later years on microscopic examination were found rich in these minerals, Rosenbusch finally gave the name its above definition and this is its generally accepted signification.

Normal metamorphism, *i. e.*, regional metamorphism. See p. 123.

Normal-pyroxenic, Bunsen's name for his assumed, typical, basic, igneous magma with 48 per cent. SiO_2 as contrasted with the corresponding *normal-trachytic* one with 76 per cent. SiO_2. He sought to explain all intermediate rocks by the intermingling of these two. Although apparently applicable at times and serviceable in their day, the conceptions have long since been exploded. See J. Roth's Gesteinsanalysen, 1861.

Nosean, the name of the mineral is often prefixed to the names of rocks containing it.

Novaculite, excessively fine grained, quartzose rocks supposed to be consolidated, siliceous slimes and of sedimentary origin. They are especially developed in Arkansas, and are much used as whetstones. See pp. 97, 98.

O

Obsidian, a general name for volcanic glass. When used alone it implies a rhyolite-glass, but it is now much employed with a prefix as andesite-obsidian, basalt-obsidian. See p. 26.

Ocellar-structure, a microscopic term used by Rosenbusch for peculiar aggregates of small pyroxenes, that resemble eyes, buds and the like, and that are especially common in nepheline and leucite rocks. Mass. Gest., 625, 1887.

Odinite, a name given by Chelius to certain porphyritic dikes in Mt. Melibocus, which have a groundmass of plagioclase and hornblende rods, with phenocrysts of plagioclase and augite. Notizbl. Ver. Erdkunde, Darmstadt, 1892, Heft 13, p. 1.

Oikocryst, the containing crystal of the inclusions in the poikilitic texture. (Jour. Geol., 14: 704, 1906.) The inclusions are xenocrysts. The abundance of xenocrysts indicated by the terms peroikic, domoikic, xenoikic, doxenic, perxenic—ranging from few to many. (Jour. Geol., 14: 704, 1906.)

Olivine, the name of the mineral is prefixed to the names of many rocks that contain it. Olivine is of especial importance in this respect as its presence marks a more basic development in the rocks, which have it as contrasted with those which lack it.

Oolitic, a textural term for those rocks which consist of small concretions, analogous to the roe of fish. Oolites are calcareous, siliceous and ferruginous.

Opacite, a noncommittal microscopic term, less current than formerly, for minute, opaque grains observed in thin sections of rocks. They are generally regarded to-day as chiefly magnetite dust.

Ophicalcite, Brongniart's name for crystalline limestones, spotted with serpentine. See p. 152.

Ophiolite, Brongniart's name for the serpentines. See p. 152. It is also employed in America in the sense of ophicalcite as above given.

Ophite, a name given in 1798 by the Abbé Palassou to a green rock of the Pyrenees. It was later recognized to be composed of feldspar and hornblende, and still later was determined by Zirkel to be uralitized diabase. The name has chief significance to-day because used to describe the textural peculiarity of some diabases. Strictly speaking an ophitic texture is one in which rod-like or lath-shaped, automorphic plagioclase feldspars are involved in augite, as it were, in a paste, so as to form a variety of poicilitic texture, but the term was used in the first edition of this book, and is employed by many in the sense in which the diabasic texture is defined on a preceding page. The difference between the two meanings lies in the fact that in the former the augite is in excess, and the feldspar is involved in it. In the latter, the feldspar is in excess, and the augite fills the interstices between its lath-shaped crystals. The peculiar significance of these textures is that the feldspars crystallized before the augite, contrary to the usual succession. See p. 77 and p. 78.

Orbicular, a textural term for those rare rocks whose minerals have a spheroidal grouping, such as corsite and orbicular granite. See Kugel and Spheroidal.

Orbite, a name proposed by Chelius for certain diorite dikes near Orbeshöhe, Hesse, of porphyritic texture and having large phenocrysts of hornblende, biotite and plagioclase. Notizbl. Ver. Erd. Darmstadt, 1892, 1.

Orendite, a name proposed by Whitman Cross, for the peculiar leucitic rocks at Orenda Butte in the Leucite Hills, Wyo. They contain leucite and sanidine, in about equal amounts, with phlogopite and diopside as essentials. A peculiar amphibole is also present. The rock is a leucite-phonolite as the latter term is used by older writers, but the objection to calling any rock a phonolite which lacks nephelite, led to the name orendite, Amer. Jour. Sci., Aug., 1897, p. 123. Compare Madupite and Wyomingite, etc.

Orio-crystal, see Brotocrystal.

Ornoite, a dioritic rock from the Swedish locality of Ornö. It contains prevailing oligoclase, with some hornblende and very subordinate microcline and orthoclase. The accessories are apatite, magnetite, pyrite, titanite and a little prehnite. The name was given by A. Cederstrom. Geol. Foren. Forhand., XV., 108, 1893.

Orthoclase, the name of the mineral is often prefixed to the names of rocks that contain it.

Orthofelsite, a name suggested by J. J. H. Teall, for porphyritic rocks with felsitic groundmass, and phenocrysts of orthoclase. British Petrography, 291, 1888.

Orthogneiss, Rosenbusch's name for micaceous gneisses derived from igneous rocks. (Elemente der Gesteinslehre, 484, 1901.) The contrasted term is paragneiss.

Orthophyre, *i. e.*, orthoclase porphyry or porphyry proper.

Ortlerite, a name given by the Austrian geologists, Stache and von John, to certain porphyrites of the eastern Alps that resemble the old greenstones and that have plagioclase, hornblende, generally augite, and more or less basis. The range from 48–54 SiO_2. Jahrb. k. k. g. Reichsanst., 1870, 342.

Ossipyte, a name suggested by C. H. Hitchcock for a rock from Waterville, N. H., which on examination in 1871 by E. S. Dana (before the use of thin sections in America) was thought to consist of olivine and labradorite, with a little magnetite. Ossipyte is derived from "Ossipees," the name of a tribe of Indians, who formerly lived in the region. Amer. Jour. Sci., Jan., 1872, p. 49. By means of thin sections the rock was later shown to contain diallage, by G. W. Hawes, and to be a gabbro. Geol. of New Hampshire, Vol. III., Part IV., p. 166. Ossipyte was a forerunner of troctolite over which it has priority. Additional notes on the local geology will be found in the paper by L. V. Pirsson and W. N. Rice. Amer. Jour. Sci., Apr., 1911, 269–291, especially 279. The modern spelling is ossipite.

Ottrelite schists, schistose rocks with the peculiar micaceous mineral ottrelite. They are best known from the Ardennes, Belgium, but are found in New England.

Ouachitite (pronounced wáw-shee-tite), a name coined by Kemp from the Ouachita River, Arkansas, for certain, basic dikes containing, in a glassy groundmass, prevailing and often phenomenally large phenocrysts of biotite, very subordinate augite and magnetite. They also occur at Beemerville, N. J., associated with nephelite syenite. Ann. Rep. Geol. Surv. of Ark., 1890, II., 393.

Oxyphyre, Pirsson's general name for the acidic rocks. Oxyphyre is contrasted with Lamprophyre, a corresponding name for the basic rocks. The two are complementary, see Lamprophyre, and Complementary Rocks.

P

Pahoehoe, the Hawaiian word for a lava sheet, whose surface consists of smooth or fluted hummocks. It is contrasted with aa, which refers to jagged and cindery crusts. See Aa. It has been specially introduced into English speech by Capt. (now Major) C. E. Dutton. 4th Ann. Rep. Dir. U. S. Geol. Surv., 95, 1883.

Paisanite, a name proposed by Osann from the Paisano Pass, on the Southern Pacific R. R., in western Texas, for a variety of quartz-porphyry, consisting of phenocrysts of microperthitic orthoclase and rarer quartz, in a groundmass of quartz and feldspar. Occasional groups of small hornblendes (riebeckite) appear. Tscherm. Min. u. Petr. Mitth., XV., 435. Compare Comendite.

Palæophyre, Gümbel's name given in 1874, to certain porphyritic dike rocks corresponding to quartz-mica-diorites in mineralogy. They cut the Silurian strata of the Fichtelgebirge.

Palæophyrite, a name proposed by Stache and von John (compare ortlerite) for certain porphyrites in whose strongly prevailing groundmass are phenocrysts of plagioclase, hornblende and augite. Jahrb. d. k. k. g. Reichsanstalt, 1879, 342.

Palæopicrite, a name proposed by Gümbel in 1874. in his paper, "Die palæolithischen Eruptiv-gesteine des Fichtelgebirges," for picrites which were considered by him to be similar to the rocks from the Cretaceous formation, originally named picrite by Tschermak. Gümbel called his specimens palæopicrites because they occurred in Palæozoic strata. He regarded them as aggregates of olivine, enstatite, chrome-diopside and magnetite, but they are now known to be chiefly olivine and augite. More or less brown hornblende and biotite also occur.

Palagonite-tuff, an altered basaltic tuff from Palagonia, in Sicily. The name palagonite was originally applied to problematical, brown inclusions in the tuff, which were thought at first to be a definite mineral. They are now known to be a devitrified, basaltic glass. The name was given by v. Waltershausen in 1846. See Vulk. Gesteine in Sicilien und Island, 1853, 179.

Palatinite, a name proposed by Laspeyres for certain rocks in the German province of Pfalz, supposed by him to be gabbros with diallage and to be of Carboniferous age; but they have since been shown to be essentially diabases. Neues Jahrb., 1869, 516. The word is derived from the classic name of the district.

Pallasite, originally proposed by Gustav Rose for a meteorite that fell near Pallas, in Russia, has been used by Wadsworth in a wider sense for both meteoric and terrestrial, ultra-basic rocks, which in the former

average about 60 per cent. iron, and in the latter have at least more iron oxides than silica. Cumberlandite (which see) is the chief example. Lithological Studies, 1884, 68.

Panidiomorphic, Rosenbusch's term for those rocks, all of whose components possess their own crystal boundaries. Panautomorphic is a synonym.

Pantellerite, a group of rocks intermediate between the rhyolites and trachytes on the one hand, and the dacites on the other. They differ from all these in having anorthoclase as the principal feldspar. Cossyrite, a rare and probably titaniferous amphibole, occurs at the original locality on the island of Pantelleria, in the Mediterranean. See pp. 31, 43, 58. The name was given by Förstner. Zeitschr. f. Kryst., 1881, 348.

Paragenesis, a general term for the order of formation of associated minerals in time succession, one after the other. To study the paragenesis is to trace out in a rock or vein the succession in which the minerals have developed and if some are secondary after others the study brings out these relations.

Paragneiss, Rosenbusch's name for micaceous gneisses derived from sediments. (Elemente der Gesteinslehre, 484, 1901.) The contrasted term is orthogneiss.

Paramorphism, the passage of one mineral into another without change of composition, as augite into hornblende in uralitization. It is also used in connection with metamorphism to describe such thorough changes in a rock, that its old components are destroyed and new ones are built up.

Parophite, a name given by T. Sterry Hunt, Geol. Surv. Can., 1852, 95, to a rock or mineral similar to dysyntribite. The name means like serpentine.

Patic, a word derived from the French "pâte" or groundmass and used in the Quantitative System with various prefixes to describe the several porphyritic textures. Thus "perpatic," extremely rich in groundmass; "dopatic," groundmass dominant. Compare semic. (Jour.Geol., 14: 701, 1906.)

Pearl-diabase, see Variolite.

Pearlite or **Pearlstone,** see perlite.

Pegmatite, originally applied to graphic granite, but of later years used as a general name for very coarse, dike or vein granites, such as have large quartz, feldspar, muscovite, biotite, tourmaline, beryl and other characteristic minerals, and are often called giant-granite. See p. 35.

Pele's Hair, a fibrous, basaltic glass from the Hawaiian Islands, named after a local goddess.

Pelite, a general name for mud rocks, *i. e.*, shales, clays and the like.

Pencatite, see predazzite.

Per, a syllable used as a prefix in the Quantitative System to denote extreme richness in any mineral or character. It is the grade beyond dominant, as perfemic, persalic, etc.

Peridotite, granitoid rocks consisting of olivine and pyroxene with little or no feldspar. See p. 81. Many varieties has been made depending on the kind of pyroxene present, or on its absence in favor of related minerals, viz:

Olivine, augite—Picrite.
Olivine, diopside (diallage), enstatite—Lherzolite.
Olivine, enstatite—Saxonite, harzburgite.
Olivine, enstatite, augite—Buchnerite.
Olivine, augite, garnet—Eulysite (metamorphic?).
Olivine, diallage, hornblende—Wehrlite.
Olivine, hornblende—Cortlandtite.
Olivine, biotite—Mica-peridotite.
Olivine, hornblende (secondary?), biotite—Scyelite.
Olivine, alone or with chromite—dunite.

Further particulars about each of these will be found under the individual names. Compare also kimberlite.

Perknite, a name from the Greek word for dark, and proposed by H. W. Turner as a collective term for the rocks usually called pyroxenites and hornblendites. Mineralogically the perknites consist briefly of monoclinic pyroxene and amphibole with subordinate orthorhombic pyroxene, olivine and feldspar. Chemically they are lower in alumina and alkalies than the diorites and gabbros, and lower in magnesia than the peridotites. Jour. of Geol., IX., 507, 1901.

Perlite, volcanic glass and concentric, shelly texture and usually with a notable percentage of water. See p. 26.

Perthite, a name given by Thomson *Phil. Mag.*, 1843, 188) to parallel intergrowths of orthoclase and albite, originally described from Perth, Ontario.

Petrical, L. Fletcher's name for the coarser structural features of rocks. See lithical.

Petrogenesis, that branch of geology which deals with the origin of rocks.

Petrographic Province, an area whose igneous rocks, of whatever type, are characterized by some distinctive feature, such as richness in soda, or potash or lime. Thus Alfred Harker has concluded that the igneous rocks around the Atlantic Ocean are relatively rich in the alkalies;

while those bordering the Pacific are relatively rich in lime. He speaks of the Atlantic province and the Pacific province in consequence. In a more restricted sense the region just east of or just within the Rocky Mountains has a long succession of rich soda rocks—phonolites, etc., in Montana, Colorado, Texas and Tamaulipas. See p. 91.

Petrography, properly the descriptive part of the science of rocks for which the more general name is petrology or lithology, but petrography is widely used as a synonym of the latter.

Petrosilex, an old name for extremely fine, crystalline porphyries and quartz-porphyries and for those finely crystalline aggregates we now know to be devitrified glasses; also for the ground masses of the former, which though not glassy are yet not resolvable by the microscope into definite minerals. See felsite, micro-felsite. It was practically a confession by the older petrographers, that they did not know of what the rock consisted.

Phacolite, a mass of intrusive rock which enters the crest of an anticline or the trough of a syncline and assumes a shape like a lentil or half a dried pea. In igneous rocks the term is analogous to "saddle reefs" in ore-deposits and is derived from the Greek words for lentil and rock. A. Harker, Nat. Hist. Ign. Rocks, 77, 1909.

Phaneric, textures in igneous rocks which are evident to the unaided eye. Its contrasted term is aphanitic. (Jour. Geol., 14: 693, 1906.)

Phanerohyaline, obviously glassy, igneous rocks. (Jour. Geol., 14: 693, 1906.)

Phenocrysts, a name suggested by J. P. Iddings (Bull. Phil. Soc. Wash., XI., 73, 1889), for porphyritic crystals in rocks. It has proved an extremely convenient one, although its etymology has been criticized. It may be best to change to phanerocryst, just as in botanical usage, phenogam has yielded to phanerogam; but one form or the other is a necessity.

Phonolite, volcanic rocks, of porphyritic or felsitic texture, consisting of orthoclase, nephelite, pyroxene and more rarely, amphibole. Leucite may replace the nephelite and yield leucite-phonolites. See p. 46. The name is Klaproth's rendering into a Greek derivative of the old name Clinkstone. Abhandl. Berlin. Akad., 1801.

Phosphorite, massive calcic phosphate, of the composition of apatite but usually lacking crystal form.

Phosphorolite, Wadsworth's name for phosphatic rocks, guano-phosphorite, apatite, etc. Rept. State Geol. Mich., 1891–92, p. 93.

Phthanite, Hauy's name for silicious schists. Its use has recently been revived in America by G. F. Becker, who applies it to certain

silicified shales in California. Quicksilver deposits of the Pacific coast, Mono. XIII., 105, U. S. Geol. Survey.

Phyllite, a name for intermediate rocks between the mica schists and slates, usually finely crystalline; mica-slates. See p. 139.

Phyre, a modification of the last syllable of porphyry, often used with prefixes, as vitrophyre, orthophyre, granophyre, etc.

Picrite, a name originally given by Tschermak to certain porphyritic rocks from the Carpathians, that have abundant and large phenocrysts of olivine, with less pyroxene, hornblende and biotite, in a glassy groundmass, more or less divitrified. The rocks are practically pre-tertiary limburgites. Picrite is now also applied to those peridotites that consist of olivine and augite. It is derived from the Greek for bitter, in allusion to the high percentage of magnesia, Bittererde in German.

Pilandite, a porphyritic phase of hatherlite.

Pistazite, a synonym of epidote, more current in Europe than America, and used in rock names for epidote.

Pitchstone, a glassy rock, usually corresponding to the rhyolites or trachytes, but with a considerable percentage of water, 5–8 per cent. for example. It was formerly specially used for pretertiary glasses, *i. e.*, the glasses of quartz-porphyries and porphyries, but time distinctions are obsolete. Pitchstones have a marked resinous luster as the name implies. See p. 26.

Plagiaplite an aplitic dike rock, consisting of acidic plagioclase, quartz and a little hornblende. (L. Duparc and S. Jerchoff, Arch. Sci. phys. et nat. Geneva, Feb., 1902, cited by Rosenbusch, Mikr. Phys., 4th ed., II., 590.)

Planophyric, having the phenocrysts of a porphyritic rock, arranged in layers. (Jour. Geol., 14: 703, 1906.)

Plumasite, a dike-rock consisting essentially of oligoclase and corundum. It cuts peridotite near the Diadem mine, Plumas Co., California, and was first described and named by A. C. Lawson, Bull. Dept. Geology, Univ. of Calif., III., 219, 1903.

Plutonic, a general name for those rocks that have crystallized in the depths of the earth, and have therefore assumed as a rule, the granitoid texture. See p. 16

Pneumatolitic, a general name for those minerals which have been produced in connection with igneous rocks through the agency of the gases or vapors called mineralizers. They may be in the igneous mass itself or in cracks in the wall rock. Compare the cases cited on pp. 125, 130. The term is much used in discussions of ore deposits.

Poicilitic, *i. e.*, speckled, a term proposed by G. H. Williams for

those rocks which have mottled luster, because on the shining cleavage faces of some of their minerals, small inclusions of others occur, producing the effect. The same thing was earlier called "luster mottling" by Pumpelly, but poicilitic has proved a useful term both in megascopic and microscopic work. (Journal of Geology, I., 176, 1893.) It is also spelled poikilitic and poecilitic.

Porcellanite, fused shales and clay, that occur in the roof and floor of burned coal seams. The rock is quite common in the lignite districts of the West, where apparently spontaneous combustion has fired the seams in the past.

Porodine, Breithaupt's name for amorphous rocks, such as are derived from gelatinous silica.

Porodite, Wadsworth's name proposed in 1879, for all the altered, fragmental forms of eruptive rocks, commonly called diabase tuff, schalstein, etc. Bull. Mus. Comp. Zoöl., 1879, V., 280.

Porphyrite, a porphyritic rock, belonging to the plagioclase series and corresponding in mineralogy to the diorites. To distinguish it from andesite, it is necessary to draw a contrast between surface flows (andesites) and intruded dikes or sheets (porphyrites); or between tertiary and later lavas (andesites) and pretertiary ones (porphyrites); or between those with glassy or very finely crystalline groundmasses (andesites) and those with groundmasses of moderate coarseness (porphyrites).

Porphyritic, a textural term for those rocks which have larger crystals (phenocrysts) set in a finer groundmass, which may be crystalline or glassy, or both. See p. 16. Rosenbusch has sought to define it as the texture due to the recurrence of the period of crystallization of the same or similar minerals (Neues Jahrb., 1882, II., 3). While, except for porphyritic rocks with a glassy groundmass, this practically amounts to the same thing as the textural definition just given, it is idle for any writer to try to change so old, well-established and indispensable a conception.

Porphyry, a word derived from the classic name of the mollusc, a species of Murex, that yielded the Tyrian purple of the ancients. It was later applied to the red, porphyritic rock of the Egyptian quarries, "porfido rosso antico," whose red color is due to piedmontite, a manganese epidote. In course of time it was applied to all porphyritic rocks as we now understand the term. In its restricted sense it implies orthoclase-porphyry, the porphyritic rock corresponding to syenite, but to give it any essential significance as contrasted with trachyte, one of the three distinctions must be drawn, which are cited above under porphyrites, and of which the second is of no real value. See p. 43. Por-

phyry is colloquially used for almost every igneous rock in the West, that occurs in sheets or dikes in connection with ore bodies.

Porphyroid, metamorphic rocks with porphyritic texture, *i. e.*, with phenocrysts of feldspar or other minerals in a finer groundmass, yet shown by geological relations to be altered sediments, or tuffs. Fossil remains have even been detected in some. They are close relatives of hälleflintas.

Pozzuolane, a leucitic tuff, found near Naples and used for hydraulic cement.

Predazzite, a contact rock at Predazzo in the Tyrol, produced from crystalline dolomite by an intrusion of syenite. It is partly calcite and partly brucite or hydromagnesite. Pencatite is the same aggregate, darkened by grains of pyrrhotite.

Primary, an old synonym of Archean. The word is also used for those rocks which have crystallized directly from fusion or solution, as contrasted with transported or secondary sediments; and for the minerals of an igneous or metamorphic rock, which, originating *in situ*, date from the crystallization of the rock itself; as contrasted with secondary minerals produced in alteration, or weathering. See p. 12.

Prismoid, textures in igneous rocks whose components are prismatic. They may be parallelopipedons, lath-shaped blades, prisms, spindles or fibers. (Jour. Geol., 14: 699, 1906.)

Propylite, a name given by von Richthofen in 1867 to certain andesites, formed at the beginning of Tertiary time, that were thought to resemble the old diorites, and diorite-porphyrites. They had been previously called by him greenstone-trachytes in Hungary, but were not named propylite until he met them again in Nevada and California (Memoirs of the California Academy of Sciences, I., 60, 1867). The western propylites have been since conclusively shown by several American petrographers to be only more or less altered andesites. The literature of the name furnishes an interesting and amusing exhibition of the efforts of those petrographers, who were influenced by the time-myth in the classification of igneous rocks, to draw distinctions, where there were no differences. The name means before the gates, alluding to their position at the beginning or entrance to the Tertiary, which was supposed to usher in the true, volcanic eruptions of geological time.

Proteolite, an old name for certain contact rocks produced by granite intrusions from slates in Cornwall. It has been lately revived by Bonny for andalusite-hornfels. (Quar. Jour. Geol. Soc., 1886, 104.) Compare Cornubianite.

Proterobase, originally applied by Gümbel 1874, to Silurian or ear-

lier diabases with hornblende. The frequency of the paramorphism of augite to hornblende has led others to apply it to diabases with uralitized augite. Rosenbusch restricts it to diabases with original hornblende.

Protogine, an old name for a granite or gneiss in the Alps, consisting of quartz, orthoclase and chlorite or sericite, the last-named of which was formerly erroneously taken for talc. The laminated structure from dynamic metamorphism is often pronounced.

Psammites, a general name for sandstones, from the Greek word for a grain of sand.

Psephites, a general name for conglomerates and breccias, *i. e.*, coarse, fragmental rocks as contrasted with psammites and pelites. The name is derived from the Greek for pebble.

Pseudo-diabase, a name proposed by G. F. Becker for certain metamorphic rocks in the Coast ranges of California that are supposed to have been derived from sediments, yet that have the minerals and texture of diabase. Monograph XIII., U. S. Geol. Surv., p. 94. Compare Metadiabase, which means the same thing and has precedence.

Pseudo-diorite, dioritic rocks produced as described under pseudodiabase above. See the same reference.

Pseudo-chrysolite, synonym of moldauite, bouteillenstein.

Pseudomorph, the replacement of one mineral by another, such that the form of the first is preserved by the second, despite the difference in composition.

Puddingstone, conglomerate.

Pulaskite, a special name given by J. Francis Williams to certain syenitic rocks from Pulaski County, Arkansas, that have trachytic texture and that consist of orthoclase (kryptoperthite), hornblende (arfvedsonite), biotite and a little augite (diopside), eleolite, sodalite and accessory minerals. Ann. Rep. Geol. Surv. Ark., 1890, II., 56. Compare laurvikite.

Pumice, excessively cellular, glassy lava, generally of the composition of rhyolite. See p. 26.

Pyroclastic, fragmental rocks such as tuffs and breccias, produced by explosive, igneous action.

Pyrogenic, a general name proposed by A. W. Grabau for the igneous rocks, *i. e.*, those which originate through the agency of heat. The name makes one in a logical group, pyrogenic; hydrogenic; atmogenic.

Pyromeride, a name given by the Abbe Haüy to the orbicular diorite or corsite of Corsica. The word means "partly fusible," and refers to the properties of the two constituent minerals, of which the one, quartz, was infusible, and the other, the feldspar, could be melted.

Pyrosehists, a name suggested by T. Sterry Hunt for those sediments that are impregnated with combustible, bituminous matter. Amer. Jour., March, 1863, 159

Pyroxene, the name of the mineral is often prefixed to the name of the rocks that contain it.

Pyroxenite, a name first proposed by T. Sterry Hunt for the masses of pyroxene occurring with the apatite deposits of Canada. It is now generally employed in the sense advocated by G. H. Williams, for granitoid, non-feldspathic rocks, whose chief mineral is pyroxene, and which lack olivine. See p. 81. (Amer. Geologist, July, 1890, p. 47.) Williams proposed the name websterite, from Webster, N. C., for a variety consisting of diopside and bronzite, with the latter porphyritically developed. Idem, 35. Compare perknite.

Q

Quantitative System, a system for the classification of the igneous rocks, proposed in its completed form in 1903 by Whitman Cross, J. P. Iddings, L. V. Pirsson and H. S. Washington. It is primarily based on the quantitative relations of the rock-making minerals in the igneous rocks as their relative percentages by weight may be calculated, measured or otherwise determined. The usual method is to recast a chemical analysis by the methods explained on earlier pages, but when, from lack of data, this proves impossible, so-called standard minerals are used which are not necessarily and are seldom actually in the rock. The system has proved of great value in bringing our relationships among rocks of which satisfactory chemical analyses have been prepared, and is specially adapted to more advanced methods of research. (See Quantitative Classification of Igneous Rocks, Chicago, 1903. G. I. Finlay, Calculation of the Norm in Igneous Rocks. Jour. Geology, 18: 58–92, 1910.)

Quartz, the name of the mineral is prefixed to the names of many rocks that contain it, as quartz-porphyry, p. 31; quartz-diorite, p. 59, etc.

Quartz-diorite, an igneous rock, of a granitoid texture, chief feldspar plagioclase, essential quartz, usually some orthoclase; dark silicates biotite, hornblende or augite, one or several; deep-seated equivalent of the dacites; closely related to grano-diorites and quartz-monzonites.

Quartzite, metamorphosed sandstone. See p. 144. Not to be used for vein quartz.

Quartz-monzonite, igneous rocks, of granitoid texture, of mineralogy intermediate between syenites and diorites (see monzonite) and with some quartz, but not enough to make them grano-diorites.

Quartz-porphyry, an igneous rock of porphyritic texture; chief phenocrysts quartz and orthoclase; usually some plagioclase; subordinate biotite, hornblende or augite, one or several; groundmass felsitic or finely crystalline, rarely glassy. The name was formerly restricted to pre-tertiary rocks, but this usage is obsolete. The name has been used for intrusive dikes and sheets as contrasted with the rhyolites, which are characteristic surface flows. In the previous pages it is replaced by rhyolite-porphyry, but it is still and for many years will remain a widely used field-name.

R

Radial Dikes, a descriptive term specially used by L. V. Pirsson for those dikes which radiate outward from an eruptive center. Amer. Jour. Sci., Aug., 1895, p. 116.

Reaction-rims, a term mostly used in microscopic work, for the curious rims of hypersthene, garnet, hornblende, biotite, magnetite and perhaps other minerals, that surround grains of magnetite or of ferromagnesian silicates, wherever, in many gabbros, they would otherwise come next to feldspar. They are supposed to be produced by the reaction of these latter minerals on each other, probably in the crystallization of the rock. A synonym is corona-structure. (See J. F. Kemp, Bull. Geol. Soc. of Amer., V., 221, 1894.)

Regional-metamorphism, Daubree's name for that extended metamorphism that, as contrasted with contact effects, is manifested over large areas. See pp. 131–133.

Regolith, a name coined by G. P. Merrill from two Greek words meaning "blanket of stone" for the layer of loose materials that mantles the land areas of the globe and rests on the solid rocks. These materials are derived from the decay of rocks, accumulations of vegetation, talus, débris, sediments, wind-blown sands and glacial deposits. Rocks, Rock-weathering and Soils, 299, 1897.

Rensselaerite, E. Emmons' name for a talcose rock from St. Lawrence Co., N. Y. Annual report of the N. Y. Geol. Survey, 1837, p. 152.

Resorbed, a term used in microscopic work to describe those phenocrysts which after crystallization are partly fused again into the magma. See p. 21.

Retinite, the current name for pitchstone among the French.

Rhomben-porphyries, a name applied to certain Norwegian porphyries, whose phenocrysts of orthoclase are bounded by ∞P and $2P\bar{\infty}$, so that they resemble a rhombohedron. The orthoclase is rich in soda.

Rhyocrystal, see Brotocrystal.

Rhyolite, volcanic rocks of porphyritic or felsitic texture, whose phenocrysts are prevailingly orthoclase and quartz, less abundantly biotite, hornblende or pyroxene, and whose groundmass is crystalline, glassy, or both. The name is from the Greek to flow, and refers to the frequent flow structure. Rhyolite is current in America, whereas liparite and quartz-trachyte are more used abroad. The name was given in 1860 by v. Richthofen. (Jahrb. d. k. k. Reichsanst., XI., 153, 1860.)

Rill-marks, small depressions in sandstones, produced by the eddying of a retreating wave on a seabeach under the lee of some small obstruction, such as a shell or pebble.

Ripple-marks, corrugations in sandstones produced by the agitation of waves or winds, when the rock was being deposited.

Rizzonite, a name derived from a locality, in the Monzoni region, and suggested by Doelter and Went for a limburgite dike. (Sitzungsber. Wiener Akad., Jan. 15, 1903.)

Rockallite, a name proposed by J. W. Judd for a rock from Rockall Island, a small reef in the North Atlantic, 240 miles west of Ireland. Rockallite is a granitoid rock, consisting of quartz, albite and ægirite, in proportions respectively of 38 : 23 : 39, in the specimen investigated. Trans. Royal Irish Academy, XXXI., Part III., 39; Amer. Jour. Sci., March, 1899, 241.

Rock-flour, a general name for very finely pulverized rocks or minerals which lack kaolinite and, therefore, the plasticity of clay, and which are much finer than sand. Rock-flour which is largely pulverized quartz, may be separated from most clays.

Routivarite, a name derived from the famous Swedish locality Routivara, where titaniferous iron ores, with abundant spinel, occur. It was applied by H. Sjögren to a phase of rock bordering on the ore and consisting of striated and unstriated feldspar, quartz and garne (Geol. För. i. Stockholm. Forh., XV., 62, 1893.)

Rudite, a general name suggested by A. W. Grabau for very coarse sediments, analogous in size of components to rubble-masonry, which the name means. Prefixes such as calci-rudite and silico-rudite, describe the components of the aggregate. Calci-rudite has been applied with special significance to those coarsely fragmental limestones produced by the breaking down of coral reefs. (Bull. Geol. Soc. Amer., 14: 348.)

S

Saccharoidal, a term applied to sandstones whose texture resembles that of old-fashioned loaves of sugar.

Sagvandite, a curious rock from near Lake Sagvand, Norway, that is mainly bronzite and magnesite. A little colorless mica, and more or less chromite and pyrite are also present. The name was given by Petterson. Neues Jahrb., 1883, II., 247.

Sahlite, a variety of pyroxene, sometimes prefixed to rock names.

Salband, a term current among miners for the parts of a vein or dike next to the country rock.

Salfemic, rocks on the border between salic and femic. See salic below.

Salic, a name coined from silica-alumina and first used in the Quantitative System for those igneous rocks with predominant light colored minerals, *i. e.*, quartz and feldspars and for the minerals themselves. Its antitheiss is femic. Salic and femic have proved very useful being shorter and more practicable than leucocratic and melanocratic, or in the case of femic, than ferromagnesian.

Sand, incoherent fragments of minerals or rocks of moderate size, say one-quarter of an inch (6 mm.) and less in diameter. Quartz is much the commonest mineral present. See p. 97.

Sandstone, consolidated sands. See p. 97.

Sanidinite, a name applied especially to certain trachytic bombs that occur in tuffs in the extinct volcanic district of the Laacher See, Germany. Recently it has been suggested by Weed and Pirsson for the extreme case of feldspathic syenites, in which all other minerals except orthoclase practically fail. They establish a series as follows:

All orthoclase, no augite—Sanidinite.
Orthoclase exceeds augite—Augite-syenite.
Orthoclase equals augite—Yogoite.
Augite exceeds orthoclase—Shonkinite.
All augite, no orthoclase—Pyroxenites of various types.

Amer. Jour. Sci., Dec., 1895, p. 479. Subsequently yogoite was withdrawn in favor of monzonite, which has priority but which is now used in a different sense. Idem, May, 1896, 357, 358.

Santorinite, a name proposed by H. S. Washington for those exceptional andesitic or basaltic rocks, which, with a high percentage of silica (65–69), yet have basic plagioclases, of the labradorite-anorthite series. The name was suggested by the volcano Santorini. (Journal of Geology, V., May–June, 1897, 368.) See also Fouqué, Santorini et ses Eruptions, Paris, 1879, and Etude des Feldspaths, 317–320. The prevailing bisilicate at Santorini is pyroxene.

Sanukite, Weinschenk's name for a glassy phase of andesite that contains bronzite, augite, magnetite, and a few large plagioclases and

garnets. The rock is related to the andesites as are the limburgites to the basalts. Neues Jahrb. Beilageband, VII., 148, 1891.

Saprolite, a name suggested by G. F. Becker for those superficial deposits produced by the decay of rocks and remaining as residuals. It is in a measure synonymous with laterite. Compare also regolith. Saprolite is from the Greek for "rotten rock." (16th Ann. Rep. U. S. Geol. Survey, 3: 289, 1895.)

Saussurite-gabbro, gabbro whose feldspar is altered to saussurite. See p. 141.

Saxonite, Wadsworth's name for peridotites consisting of enstatite or bronzite and olivine. It is a synonym of harzburgite, but saxonite has priority. Lithological Studies, 1884, p. 85.

Schalstein, an old name for a metamorphosed diabase tuff.

Schiller-fels, enstatite or bronzite peridotite with poicilitic pyroxenes. Orthorhombic pyroxenes possess the poicilitic texture to a peculiar degree, and especially when more or less altered to bastite. The term schiller, which expresses this, is especially appropriate for them.

Schillerisation, Judd's name for the process of producing poicilitic texture by the development of inclusions and cavities along particular crystal planes. The cavities are largely produced by solution, somewhat as are etch figures, and are afterwards filled by infiltration. Quart. Jour. Geol. Soc., 1885, 383; 1886, 82.

Schist, thinly laminated, metamorphic rocks which split more or less readily along certain planes approximately parallel. See p. 137.

Schlieren, a useful German term, largely adopted into English, for those smaller portions of many igneous rocks, which are strongly contrasted with the general mass, but which shade insensibly into it. Thus portions of granite are met, much richer in biotite and hornblende than the normal rock, or much more coarsely crystalline. Pegmatite streaks occur and other differentiations of the original magma. Several different varieties may be made, for a discussion of which see Zirkel's Lehrbuch der Petrographie, I., 787, 1893.

Schorl, an old name for tourmal ne, still sometimes used in names of rocks.

Schriesheimite, a dike-rock of the composition of amphibole-peridotite and having a marked poikilitic texture. It was named from the Schriesheim valley near Heidelberg. (H. Rosenbusch, Mikros. Phys., 4th ed., II., 458.)

Scoria, coarse, cellular lava, usually of basic varieties.

Scyelite, Judd's name for a rock, related to the peridotites, that occurs near Loch Skye, in Scotland. Its principal mineral is green hornblende,

presumably secondary after augite; with it are bleached biotites, together with serpentine, supposed to be derived from olivine. See Quar. Jour. Geol. Soc., 1885, 401.

Secondary, a term used both for rocks and minerals, that are derived from other rocks and minerals. Examples are sandstone, clay, or other sediments; chlorite from augite, etc. See the contrasted word primary.

Sedimentary, rocks whose components have been deposited from suspension in water. See p. 92.

Selagite, a name of Hauy's for a rock consisting of mica, disseminated through an intimate mixture of amphibole and feldspar, but it has been since applied to so many different rocks as to be valueless.

Selenolite, Wadsworth's name for rocks composed of gypsum or anhydrite. Rept. State Geol. of Mich., 1891–92, p. 93.

Semic, a word derived from the French "semé," meaning sown or sprinkled, and used for those porphyritic textures which are sprinkled with phenocrysts; "sempatic," phenocrysts and groundmass approximately equal, dosemic, phenocrysts dominate; persemic, extremely rich in phenocrysts. (Jour. Geol., 14: 701, 1906.)

Septaria, literally little walls, a name applied to concretions, largely of argillaceous material, which are traversed by cracks. The cracks are filled as a rule with calcite or quartz, affording an intersecting network from which weathering may have removed the original, included, argillaceous matter.

Seriate, inequigranular textures in igneous rocks, whose components vary gradually or in a continuous series. (Jour. Geol., 14; 700: 1906.) When the sizes are abruptly contrasted or in broken series the term is hiatal.

Sericite-schist, mica-schist whose mica is sericite. See p. 139. Sericite is also used as a prefix to many names of metamorphic rocks containing the mineral.

Serpentine, a metamorphic rock consisting chiefly of the mineral serpentine. See p. 150.

Shastalite, Wadsworth's name for unaltered, glassy forms of andesite. Rept. of Mich. State Geol., 1891–92, p. 97.

Shonkinite, a name given by Weed and Pirsson to a rock from the Highwood Mountains, Mont., which they define as "a granular, plutonic rock consisting of essential augite and orthoclase, and thereby related to the syenite family. It may be with or without olivine, and accessory nepheline, sodalite, etc., may be present in small quantities." Bull. Geol. Soc. Amer., VI., 415, 1895. See Anal. 7, p. 42. Later they state that augite should exceed orthoclase. Amer. Jour. Sci., Dec., 1895, p. 479.

Shoshonite, a general name proposed by Iddings for a group of igneous rocks in the eastern portion of the Yellowstone Park. They are porphyritic in texture, with phenocrysts of labradorite, augite and olivine, in a groundmass that is glassy or crystalline; in the latter case orthoclase and leucite, alone or together, are developed. Chemically they range: SiO_2, 50–56; Al_2O_3, 17–19.7; CaO, 8–4.3; MgO, 4.4–2.5; Na_2O, 3–3.9; K_2O, 3.4–4.4. The rocks are to be considered in connection with absarokite and banakite. Jour. of Geol., III., 937.

Siderolite, as used by Fletcher and generally in English, is a name for meteorites that are partly metallic iron and partly silicates. As used by others it is applied to more purely metallic ones.

Sideromelane, von Waltershausen's name for a basaltic glass from the palagonite tuffs of Sicily. Vulk. Gest. v. Sicilien und Island, 202, 1853.

Silicalite, Wadsworth's name for rocks composed of silica, such as diatomaceous earth, tripoli, quartz, lydite, jasper, etc. Rept. State Geol. Mich., 1891–92, p. 92.

Silicification, the entire or partial replacement of rocks and fossils with silica, either as quartz, chalcedony or opal.

Sillite, Gümbel's name for a rock from Sillberg, in the Bavarian Alps, variously referred by others to gabbro, diabase, mica-syenite and mica-diorite. Beschr. der bay. Alpen, 184, 1861.

Sills, an English name for an intruded sheet of igneous rock.

Silt, a general name for the muddy deposit of fine sediment in bays or harbors, and one much employed in connection with engineering enterprises.

Sinaite, an alliterative substitute for syenite proposed by Rozières because on Mt. Sinai true, quartzless syenites occur, whereas at Syene the rock is a hornblende-granite.

Skarn, a term current among the Swedish iron miners for the aggregates of basic silicates, especially hornblende, biotite and pyroxene which are associated with the magnetic ores. (Eleventh Int. Geol. Congr. Guide-book. Pamphlet 4, A. G. Högbom on Gellivare, p. 20, 1910.)

Slickensides, polished surfaces along faults, or fractures produced by the rubbing of the walls upon each other during movement.

Soapstone, metamorphic rocks, consisting chiefly of talc. See p. 153.

Soda-granite, granites especially rich in soda, or whose soda exceeds the potash. Compare analyses, p. 33. See natron-granite.

Sodalite-syenites, syenites rich in sodalite; close relatives of nephelite syenites. See Anal. 5, p. 44. Sodalite-trachytes also occur.

Soda-syenite, or sodium syenite, a syenite whose chief feldspar is albite, and in which thus the soda exceeds the potash. The most familiar illustration is the ore-bearing rock of the Treadwell mine, Alaska. The rock is chiefly albite. If now we define a syenite as an igneous rock with an alkali-feldspar, then it is a syenite. If, however, we define a diorite, as an igneous rock with plagioclase, it would be called a diorite or albite-diorite. (See G. F. Becker, 18th Ann. Rep. U. S. Geol. Surv., 3: 1, 1898.)

Soda-trachytes, trachytes rich in soda and therefore containing, albite, sodalite, soda-pyroxenes, or soda-amphiboles, and marking transitions to the phonolites.

Soggendalite, a name proposed by C. F. Kolderup for a variety of diabase that is especially rich in pyroxene, and that is intermediate between true diabases and pyroxenites. The type rock forms a dike near Soggendal, Norway. Bergens Museums Aarbog, 1896, 159.

Soil, surface earth mixed with the results of the decay of vegetable or animal matter, so as usually to have a dark color.

Sölvsbergite, Brögger's name for quartzless or quartz-poor grorudites; that is, medium to finely crystalline, dike rocks, with prevailing alkali-feldspar (mostly albite and microcline) with ægirite, or in the basic varieties with hornblende (kataforite), sometimes also with a peculiar mica. In the most basic members quartz entirely fails and nephelite appears, (Die Eruptivgesteine des Kristianiagebietes, I., 67.)

Sommaite, a name derived from Monte Somma (Vesuvius) and suggested by A. Lacroix for blocks having the composition of a leucite-olivine-monzonite. (Cited by H. Rosenbusch, Mikros. Phys., 4th ed., II., 169.)

Sondalite, a name proposed by Stache and von John for a metamorphic rock consisting of cordierite, quartz, garnet, tourmaline and cyanite. Jahrb. d. k. k. g. Reichsanst., 1877, 194.

Sordawalite, an old name for the glassy salbands of small diabase dikes. The sordawalite was regarded as a mineral. It is derived from Sordawalar, a locality in Finland. Compare wichtisite.

Sparagmite, a collective term used in Sweden for the fragmental rocks, especially feldspathic sandstones of the Swedish Jotnian or late Precambrian strata. (Geol. Guide. Eleventh International Geol. Congress, Pamphlet 2, p. 8, 1910.) Sparagmite means a fragmental rock, being derived from the Greek for fragment.

Spessartite, a name proposed by Rosenbusch, for those dike rocks, which, whether porphyritic or granitoid in texture, consist of prevailing plagioclase, hornblende and diopside. Orthoclase and olivine oc-

casionally appear. Massige Gesteine, 532, 1896. The name is derived from Spessart, a group of mountains in the extreme northwest of Bavaria, but as it has already been used for a variety of garnet, it is a very unfortunate selection.

Sphenolith, a name suggested by C. Burckhardt for a peculiar intrusive mass of dacite in the ridge called Las Parroquias near Mazapil, Zacatecas, Mexico. The mass lies between steeply dipping Jurassic and Cretaceous beds and parallel with them but its upper portion abuts sharply against the overlying beds or cuts them at a right angle. It thus forms a sort of wedge-shaped mass with a flat top and received its name from the Greek for wedge. (Geological Guide of the Tenth International Geol. Congress, Pamphlet 26, p. 33, 1906.)

Spheroidal, a descriptive term applied to igneous rocks that break up on cooling into spheroidal masses analogous to basaltic columns; also used as a synonym of orbicular as applied to certain granites.

Spherulites, rounded aggregates or rosettes, large or small, of acicular crystals that radiate from a center. They are chiefly met in the microscopic study of acidic, volcanic rocks and commonly consist of feldspars and quartz. When of one mineral they are called by Rosenbusch spherocrystals. They may reach large size, though mostly microscopic. See p. 26.

Spilite, an early French name for dense, amygdaloidal varieties of diabase.

Spilosite, a spotted, contact rock produced from shales and slates by intrusions of diabase. It corresponds to the hornfels of granite contacts. Zincken in Karsten und v. Dechen's Archiv, 1854, 584.

Stagmalite, a name, suggested by O. C. Farrington, for stalactites, stalagmites, and crustiform, cave deposits of calcite in general. (Field Columbian Museum Publications 53: 261, 1901. Geol. Series I., No. 8.)

Stalactite, depending, columnar deposits, generally of calcite, formed on the roof of a cavity by the drip of mineral solutions. Compare stalagmite.

Stalagmite, uprising, columnar deposits, generally of calcite, formed on the floor of a cavity by the drip of mineral solutions from the roof. Compare stalactite.

Steatite, soapstone, talc rocks.

Stock, a rudely cylindrical, relatively large, intrusive mass. Good illustrations will be found in the Telluride folio of the U. S. Geol. Surv. The name is an adaptation of the German word for floor or story, and originated in the Saxon tin mines, in which such igneous masses, impregnated with cassiterite were mined in horizontal slices, like floors.

Structure, used generally in America for the larger physical features of rocks, as against *texture*, which is applied to the smaller ones. See p. 16. Many, however, employ them interchangeably. Compare also petrical and lithical.

Stubachite, a name suggested by E. Weinschenk for a more or less serpentinized variety of dunite, having also diallage, tremolite, talc, magnetite, pyrite and breunnerite. (Cited by H. Rosenbusch, Mikros. Phys., 4th ed., II., 476.)

Stylolite, small, columnar developments in limestones or other calcareous rocks that run across the stratification. They appear to have been caused by some unequal distribution of pressure in consolidation, or by a capping fossil, as against the surrounding rock.

Subhedral, components of igneous rocks, which have their own crystal boundaries in part and are therefore intermediate between euhedral and anhedral. Hornblendes with prismatic crystal faces, but without terminal planes, are subhedral.

Subsoil, the layer of more or less decomposed and loose fragments of country rock that lies between the soil and the bed rock in regions not covered by transported soils.

Suldenite, a name given by Stache and von John to gray, acidic, andesitic porphyrites in the Eastern Alps. They range from 54–62 SiO_2 and have, in the prevailing gray groundmass, phenocrysts of hornblende, plagioclase, a little orthoclase and accessory augite, biotite and quartz. Compare ortlerite.

Surficial, a general name, lately introduced by the U. S. Geological Survey, for the untransported surface, alteration products of igneous rocks.

Sussexite, a special name suggested by Brögger for the eleolite porphyry, originally described by Kemp, from Beemerville, Sussex Co., N. J. Die Eruptivgesteine des Kristianiagebietes, 1895. The name was, however, applied years ago to a hydrated borate of manganese and magnesia, from Franklin Furnace, N. J.

Syenite, granitoid rocks consisting in typical instances of orthoclase and hornblende. In mica-syenites, biotite replaces hornblende. In augite-syenites, augite does the same. For etymology and history see p. 44. Compare also laurvikite, monzonite, nordmarkite, pulaskite, sanidinite, shonkinite, yogoite.

Syngenetic, see Epigenetic.

Syssiderite, Daubrée's name for those meteorites which consist of silicates cemented together by metallic iron.

T

Tachylyte, Breithaupt's name for a basaltic glass. It was originally regarded as a mineral and was named from two Greek words suggested by its quick and easy fusibility. See analyses 15, p. 25, and description, p. 26. Kastner's Archiv für die gesammte Naturlehre, VII., 112, 1826. Compare hyalomelane.

Taconyte, a name proposed by H. V. Winchell for the cherty or jaspery, but at times calcareous or more or less quartzitic rock, that encloses the soft hematites of the Mesabi Range, Minn. Taconytes are regarded as in large part altered greensands by J. E. Spurr. The term is current in the Mesabi iron range. XX. Ann. Rep. Minn. Geol. Survey, 124. The name is derived from Taconic, E. Emmons' rejected geological system.

Taimyrite, an acidic trachyte, rich in soda, and regarded as the effusive equivalent of nordmarkite. Chrustschoff; Melanges geol, et paleontol. Acad. Sci. St. Petersburg, I., 153, 1892. The original locality is in Siberia.

Talc-schist, schistose rocks consisting chiefly of talc and quartz. See p. 142. Talc is also prefixed to several other rock names.

Taspinite, a granitic rock enclosing an intrusive mass of more or less metamorphosed granite-porphyry in the Rofna valley of the Upper Rhine in Switzerland. (Cited by H. Rosenbusch, Mikros. Phys., 4th ed., II., 517.)

Taurite, a name given by A. Lagorio, to a variety of rhyolite, with granophyric or spherulitic texture, rich in soda, and containing ægirite. Guide to the Excursions, 7th International Geol. Congress, XXXIII., 27, 1897, St. Petersburg.

Tawite, a name given by W. Ramsey to a very peculiar rock of both granitoid and porphyritic texture and consisting of pyroxene and sodalite. It occurs in the nephelite-syenite area of Kola in Finland and is derived from Tawajok, a local geographical term. Fennia, XI., 2, 1894.

Taxite, Loewinson-Lessing's name for lavas, that, on crystallizing, have broken up into contrasted aggregates of minerals so as to present an apparent clastic texture—either banded, *i. e.*, eutaxitic, or brecciated, *i. e.*, ataxitic. Bull. Soc. Belg. Geol., V., 104, 1891.

Tephrite, basaltic rocks containing lime-soda feldspar, nephelite, augite and basis. Leucite-tephrites have leucite in place of nephelite, and some tephrites have both. Tephrites differ from basanites in lacking olivine. The name is from the Greek for "ashen," alluding to the color. It is an adaptation of an old form, tephrine. Neues Jahrb., 1865, 663.

Teschenite, a name given in 1861 by Hohenegger to a group of intrusive rocks in the Cretaceous strata near Teschen, Austrian Silesia. They have, however, been since shown to embrace such a variety of types, that the name has little value, but as analcite occurs quite constantly in most of them, many still use the term for diabasic rocks with this mineral.

Texture, see structure and also p. 16.

Theralite, granitoid rocks, consisting essentially of plagioclase, nephelite and augite, with the common accessories. They were first discovered by J. E. Wolff in the Crazy Mountains, Montana. They were previously and prophetically named by Rosenbusch from the Greek to seek eagerly, because this mineralogical and textural aggregate was believed to exist before it was actually discovered. A spelling therolite is also advocated.

Tholeiite, Rosenbusch's name for augite-porphyrites, which, aside from the usual phenocrysts, have a groundmass, with but one generation of crystals and with a little glassy basis between them, affording a texture called intersertal. Massige Gest., 504, 1887.

Tilaite, a name derived from a locality in the northern Urals and suggested by L. Duparc and F. Pearce for a variety of olivine gabbro, exceptionally rich in diopside. (Cited by H. Rosenbusch, Mikros. Phys., 4th ed., II., 353.)

Till, unsorted glacial deposits, consisting of boulders, clay and sand.

Timazite, a name given by Breithaupt to certain porphyritic rocks in the Timok Valley of Servia, that have since proved to be varieties of andesite and dacite. Berg. und Hüttm, Zeit., 1861, 51.

Tinguaite, a name given by Rosenbusch to rocks consisting of alkali feldspar, nephelite and abundant ægirite, which form dikes in or near areas of nephelite-syenite. It was first applied to specimens from the vicinity of Rio Janeiro, where in the Serra de Tingua the rocks were first discovered and described by O. A. Derby as phonolites. They have since proved of very wide distribution and not always to accompany nephelite-syenites (Black Hills, S. D.). By some the name tinguaite is regarded as an unnecessary and undesirable synonym of phonolite. It first appears in Hunter and Rosenbusch, Tschermarks Min. and Petrog. Mitth., XI., 447, 1890.

Tjosite, a name suggested by W. C. Brögger for a dike-rock, consisting of prevailing pyroxene, abundant apatite and magnetite, with grains of olivine, all set in a paste of anorthoclase rods. (H. Rosenbusch, Mikros. Phys., 4th ed., II., 705.)

Toadstone, an old English name for certain, intruded sheets of amyg-

daloidal basaltic rocks in the lead district of Cumberland, England. Also locally applied near Boston to a mottled felsite, apparently spherulitic.

Toellite, a biotite-hornblende-porphyrite, with garnets, that forms dikes in mica-schist and gneiss near Meran, in the Tyrol. Pichler, Neues Jahrb., 1873, 940.

Toensbergite, a name given by W. C. Brögger to certain very feldspathic, syenitic rocks, from Tönsberg, Norway, which are close relatives of the anorthosites. They differ from the anorthosites in their smaller percentages of lime and higher percentages of alkalies. Eruptivgest. d. Kristianiageb., III., 328, 1899.

Tonalite, a quartz-mica-hornblende diorite from near Meran in the Tyrol. It was named by vom Rath from Tonale, a place on Mt. Adamello. Zeit. d. d. g. Gesellsch., XVI., 249, 1864. Compare adamellite.

Topazfels, a brecciated, contact rock, near granite contacts and, formed of topaz, tourmaline, quartz and some rarer accessory minerals.

Tordrillite, a name based on the Tordrilla Mountains, Alaska, and suggested by J. E. Spurr for porphyritic varieties of alaskite, which have a finely crystalline or aphanitic groundmass. See Alaskite.

Toscanite, a name proposed by H. S. Washington for a group of acid, effusive rocks in Tuscany (Italian, *Toscana*) and elsewhere, which are characterized mineralogically by the presence of basic plagioclase, as well as orthoclase, and by occasional quartz; and chemically by high silica and alkalies, and (for the acidity) high lime, and low alumina. They range from 63–73 silica and are intermediate between rhyolites and dacites. Journal of Geology, V., 37, 1897. Compare dellenite,

Touchstone, see basanite.

Tourmaline-granite, a variety of granite with tourmaline as the dark silicate. It is usually due to fumarole action, and is developed on the borders of intrusions of normal granites.

Trachorheite, a name proposed by F. M. Endlich as a collective designation for the four rocks, propylite, andesite, trachyte and rhyolite, as used by von Richthofen. Hayden's reports, 1873, p. 319.

Trachy-andesite, effusive rocks, intermediate between trachytes and andesites. Used by H. S. Washington for trachytes which have also much acidic plagioclase (andesine to oligoclase). Jour. Geol., V., 351.

Trachy-dolerite, a name suggested by Abich for a group of rocks intermediate between the trachytes and basalts. Natur u. Zusammensetzung der vulkanischen Bildungen, 101, 1841. Compare Latite. Trachy-dolerite as used by H. S. Washington means a trachyte with considerable basic plagioclase (labradorite to anorthite). Jour. Geology, V., 351.

Trachyte, igneous rocks of porphyritic or felsitic texture consisting essentially of orthoclase and biotite or hornblende or augite, one or more. See p. 40. It was formerly used for both rhyolites and trachytes proper, or practically as a field name for light-colored lavas and porphyries. As such in older reports it is to be understood. Compare also acmite-trachytes and pantellerites.

Trachytic texture, a special microscopic name for those groundmasses that are made up of rods of feldspar, usually in flow-lines, but without basis.

Trap, a useful field name for any dark, finely crystalline, igneous rock. It is a Swedish name from the occurrence of such rocks in sheets that resemble steps, "trappar." See p. 90.

Trass, a trachytic tuff from the Laacher See, used along the Rhine for hydraulic cement.

Travertine, calcareous tufa. The name was given by Naumann and is of Italian origin.

Trichite, a microscopic term for hair-like crystallites; so named from the Greek for hair.

Tripoli, a name applied to diatomaceous earth and to pulverulent silica derived by the breaking down of cherts from some change not well understood. See p. 111.

Troctolite, Bonney's name for a variety of gabbro consisting of plagioclase and olivine with very subordinate diallage. The olivine may be serpentinized. Geol. Magazine, 1885, 439. Compare Ossipyte.

Trowlesworthite, a variety of granite which has been so altered by fumarole action that it consists of fluorite, orthoclase, tourmaline and some quartz, the last named having been largely replaced by the first. The name is derived from an English locality, and was given by Worth, Trans. Roy. Geol. Soc. of Cornwall, 1884, 180. Mineralog. Mag., 1884, 48.

Tufa, the cellular deposits of mineral springs, usually calcareous or siliceous. See p. 108. Not to be confounded with tuff.

Tuff, the finer, fragmental ejectments from the explosive eruptions of volcanoes. They may afterwards be water-sorted or cemented to firm rock. Coarser ones are called volcanic breccias, but in neither do we see much sorting unless produced by subsequent erosion. Tufa is also used in this sense, but the custom should be discouraged.

Typhonic rocks, Brongniart's name for rocks that have come from the depths of the earth, *i. e.*, plutonic and eruptive rocks. Typhon is used as a synonym of boss or stock.

U

Umptekite, a name proposed by Ramsay for the border facies of the nephelite-syenite mass at Umptek, Finland. It lacks nephelite almost entirely, and contains perthitic intergrowths of the alkali-feldspars. Arfvedsonite is the chief, dark silicate, but ægirite is also present. The accessory minerals are numerous. Fennia, XI., 2, 1894.

Unakite, a peculiar granite consisting essentially of epidote, pink feldspar and quartz. The name is derived from the Unaka range of mountains along the border of North Carolina and Tennessee, and was first given by F. H. Bradley in 1874. (Amer. Jour. Sci., May, 1874, 519.) Other localities have since been noted. (See T. L. Watson, Idem, Sept., 1906, 248.)

Uralite, a special name for that variety of hornblende, that is derived by paramorphism from augite. The word is often used as a prefix before the names of those rocks that contain the mineral. It has also suggested various rock names, such as proterobase, scyelite, etc. The name is derived from the original occurrence in the Urals. (G. Rose, Reise nach dem Ural, II., 1842, 371.)

Urtite, a name given by W. Ramsay to a light colored rock of medium grain, consisting of nephelite in largest part, with which is considerable ægirite and a little apatite. When recast an analysis gave nephelite, 82; ægirite, 16; apatite, 2. The name is derived from the second part of Lujavr-Urt, the name of the mountain where it occurs in northern Finland. Geol. Foren. Forh., XVIII., 463, 1896.

V

Valbellite, a name derived from the Valbella valley of Piedmont, and applied by R. W. Schäfer to a dike of amphibole-peridotite, consisting of olivine, brown hornblende, bronzite, pyrrhotite, spinel and magnetite. (Cited by H. Rosenbusch, Mikros. Phys., 4th ed., II., 462.)

Variolite, a special name for a curious, border development of diabase intrusions, which is a very dense, finely crystalline mass of rounded spheroids, largely spherulitic in texture. They give the rock a pock-marked aspect and hence the name, which is a very old one. Pearl diabase is synonymous.

Vaugnérite, a name derived from Vaugneray near Lyons, and applied by Fournet in 1836 to a dike-rock, which is now shown by Michel-Levy and Lacroix to be an amphibole-granite. They advise dropping the special name. (Bull. Soc. mineral de France, 1887, X., 27.)

Vein, strictly speaking, the mineral matter which has been deposited in fissures in rocks from solution. Water, assisted by dissolved sub-

stances, is the almost invariable solvent. The name was doubtless originally given because of the similarity of the ramifying and often intersecting deposits, to the veins of man and animals. Vein is contrasted with dike, which chills in a fissure from a fused condition. While the above simple statement holds true for the vast majority of cases there has yet arisen a need of expansion. We find associated with many veins, impregnation and oftentimes replacement of the walls, such that the original supply fissure is a relatively small part of the resulting deposit. We find again, veins, such as the apatite deposits of Norway, obviously formed in large part at least by vapors and gases emitted in the cooling stages of igneous rocks, in the processes called pneumatolitic. Volatilization may largely operate instead of mere solution; and replacement of the wall rocks may be extensive. Again in the formation of pegmatites we believe that the process is intermediate between solution at exalted temperatures and pressures; and fusion in the presence of abundant water vapor or dissociated hydrogen and oxygen, and other mineralizers. Some geologists describe pegmatites as dikes; some as veins. The point may also be made that since all igneous magmas are regarded as solutions, whose dissolved matters crystallize in the inverse order of their solubilities, no distinction can be drawn between veins and dikes. But at least in dikes almost the entire solvent solidifies with the dissolved matter, whereas in typical veins the solvent, water, passes on after precipitating its burden.

Ore-deposits occur so often in veins, as strictly defined above, that the prospector and miner have applied the name vein to any and every form of ore-body. The coal-miner even speaks of coal-seams as veins, although this usage is not to be commended in carefully chosen scientific language.

Venanzite, a name proposed by Sabatini, an Italian petrographer, for an effusive rock from a small volcanic cone at San Venanzo, Umbria, Italy. Venanzite contains phenocrysts of olivine in a groundmass of melilite, leucite and black mica, together with a little pyroxene, nephelite and magnetite. Bolletino Reale Comitato Geologico, Sept., 1898. Rosenbusch subsequently described the same rock under the name Euktolite, but Venanzite has priority. Sitzungsber. k. pr. Akad. Wissensch. Berlin, VII., 110, 1899; Amer. Jour. Sci., May, 1899, 399.

Verite, a name derived from the Spanish locality Vera, near Cabo de Gata, and given by Osann to a post-Pliocene glassy rock, with phenocrysts of biotite and microscopic crystals of olivine and augite and sometimes plagioclase, all of which seldom form half the mass of the rock. It is a glassy variety of the mica-andesites with exceptional olivine. Z. d. d. g. G., XLI., 311, 1889. Compare Fortunite.

Vintlite, a quartz-porphyrite occurring in dikes near Unter-Vintl, in the Tyrol. Compare toellite from the same region. Pichler, Neues Jahrb., 1871, 262.

Viridite, a microscopic name suggested by Vogelsang and formerly used for the small, green, chlorite scales often met in thin sections. As their true nature has now been determined, they are generally called chlorite.

Vitro, a prefix meaning glassy and used before many rock names, as vitrophyre, in order to indicate a glassy textur .

Vitrophyre, Vogelsang's name for quartz-porphyries and porphyries with glassy groundmass.

Vogesite, Rosenbusch's name for syenitic dikes, in which the dark hornblendes or augites are in excess over the light colored feldspars. Mass. Gest., 1887, 319. The name is derived from Vogesen, the German form of Vosges.

Volcanic, surface flows of lava as distinguished from plutonic rocks, see p. 16.

Volcanite, a name proposed by W. H. Hobbs, for an anorthoclase-augite lava with the chemical composition of dacite. Bull. Geol. Soc. Amer., V., 598. The name was suggested by the original occurrence on the island of Volcano, one of the Lipari group, where the rock is met as cellular bombs.

Volhynite, a porphyrite containing plagioclase, hornblende and biotite phenocrysts in a holocrystalline groundmass of feldspar and chlorite. The name was given by Ossovsky, and it is based on the original occurrence in Volhynia. See Chrustschoff, Bull. Soc. Min. France, 1885, 441.

Vulsinite, a name suggested by H. S. Washington for a group of rocks intermediate between trachytes and andesites. They contain much labradorite in addition to the usual minerals of trachyte. The name is derived from the Vulsinii, an ancient Etruscan tribe inhabiting the region where the type specimens were obtained. Journal of Geology, IV., 547. Compare latite and trachydolerite.

W

Wacke, an old name for the surficial, clayey products of the alteration of basalt. The syllables are still current in graywacke.

Wash, a miner's term in the West for loose, surface deposits of sand, gravel, boulders, etc.

Websterite, a name proposed by G. H. Williams for the pyroxenites near Webster, N. C., that consist of diopside and bronzite, with the

latter porphyritically developed. Amer. Geol., VI., 35, 1890. The name websterite had been previously used by A. Brongniart in 1822 for aluminite. Hauy's Mineralogie, II., 125.

Wehrlite, a name originally suggested by von Kobell for what was supposed to be a simple mineral, but which proved to be a peridotite consisting of olivine and diallage.

Weiselbergite, Rosenbusch's name for those augite-porphyrites whose groundmass consists of a second and sometimes third generation of plagioclase rods and augites, arranged in flow lines in a glassy basis. Mass. Gest., 501, 1887. Wadsworth uses the name for an altered andesite glass. Rept. of State Geol. of Mich., 1891–92, p. 97.

Whinstone, a Scotch name for basaltic rocks.

Wichtisite, a glassy phase of diabase, named from a Finland locality, Wichtis. Compare sordavalite.

Windsorite, a name derived from Windsor, Vt., and applied by R. A. Daly to a dike rock "leucocratic, hypidiomorphic-granular, composed essentially of alkaline feldspar (microperthite and orthoclase), basic oligoclase, quartz and biotite, and characterized by high alkalies (potash slightly in excess of soda), relatively low lime (contained essentially in the plagioclase), low iron and low magnesia." (Bull. 209, U. S. Geol. Survey, 48, 1903.)

Wyomingite, a name suggested by Whitman Cross, for the variety of rock from the Leucite Hills, Wyoming, which consists almost entirely of leucite and phlogopite. Small, acicular crystals of diopside are very subordinate, and apatite is also present. Amer. Jour. Sci., Aug., 1897, 120. This is the rock described by Zirkel in 1876 and was the first known occurrence of leucite in America. Fortieth Parallel Survey, VI., 259.

X

Xenogenites, Posepny's term for mineral deposits of later origin than the wall rock. The name means foreigners, and refers to their later introduction. Compare idiogenites. Trans. Amer. Inst. Min. Eng., XXIII., 205, 1893.

Xenolith, a term proposed by W. J. Sollas, for included masses of rock, caught up in an igneous intrusion. The term means foreign rock. Xenoliths have been subdivided by Alfred Harker into *accidental*, or bodies foreign to the enclosing magma; and *cognate*, or bodies contrasted with the normal magma but derived from it in earlier stages. In illustration of the latter we may cite glomeroporphyritic aggregates, basic segregations, orbicular or spheroidal granites, and the olivine-knollen of the basalts. Cognate xenoliths of single individual crystals

may be called xenocrystals, such as the occasional quartz in basalt. Nat. Hist. Ig. Rocks, 346.

Xenomorphic, Rohrbach's textural name for those minerals in an igneous rock whose boundaries are determined by their neighbors. Its antithesis is automorphic, which see. Xenomorphic is synonymous with allotriomorphic, over which it has priority. Tsch. Mitt., 1886, 18.

Yamaskite, a name derived from Mt. Yamaska, Prov. Quebec, and applied by G. A. Young to a very basic igneous rock of granitoid texture and consisting of pink, pleochroic pyroxene, basaltic brown hornblende, anorthite and ilmenite. It has less than 40 per cent. silica and is chemically near iacupirangite. (Ann. Rep. Geol. Surv. Canada, 17: Part II., 1907.)

Y

Yentnite, a name derived from the Yentna River, Alaska, and suggested by J. E. Spurr for certain granitoid rocks, consisting of oligoclase, scapolite and biotite, with a few zircons. The scapolite is believed to be an original mineral. Amer. Jour. Sci., Oct., 1900, 310.

Yogoite, a name suggested by Weed and Pirsson from Yogo peak, one of the Little Belt Mountains, Mont., for a syenitic rock composed of orthoclase and augite in about equal amounts. See also sanidinite and shonkinite. Amer. Jour. Sci., Dec., 1895, 473–479.

Yte, a substitute for ite, proposed by J. D. Dana, so that by using it in rock-names they would be at once distinguished from mineral names, otherwise, in some instances the same.

Z

Zircon-syenite, a name originally given by Hausmann to certain Norwegian nephelite-syenites which were rich in zircons. Later it was practically used as a synonym of nephelite-syenite, but is now obsolete.

Zirkelite, a name proposed by Wadsworth in 1887 to designate altered, basaltic glasses, in distinction from their unaltered or tachylitic state. Geol. Surv. Minn. Bull., 2, 1887, p. 30.

Zobtenite, Roth's name for metamorphic rocks with the composition of gabbros, *i. e.*, rocks not certainly igneous. The name is derived from the Zobtenberg, a Silesian mountain. Sitz. Berl. Akad., 1887, 611.

Zonal-structure, a term especially used in microscopic work to describe those minerals whose cross-sections show their successive, concentric layers of growth.

Zwitter, a Saxon miner's term for a variety of greisen. Only of significance in connection with tin ores.

INDEX.

NOTE.—The index only concerns the main portion of the book and not the Glossary. Attention may be called to the latter as embracing many rocks not otherwise mentioned.

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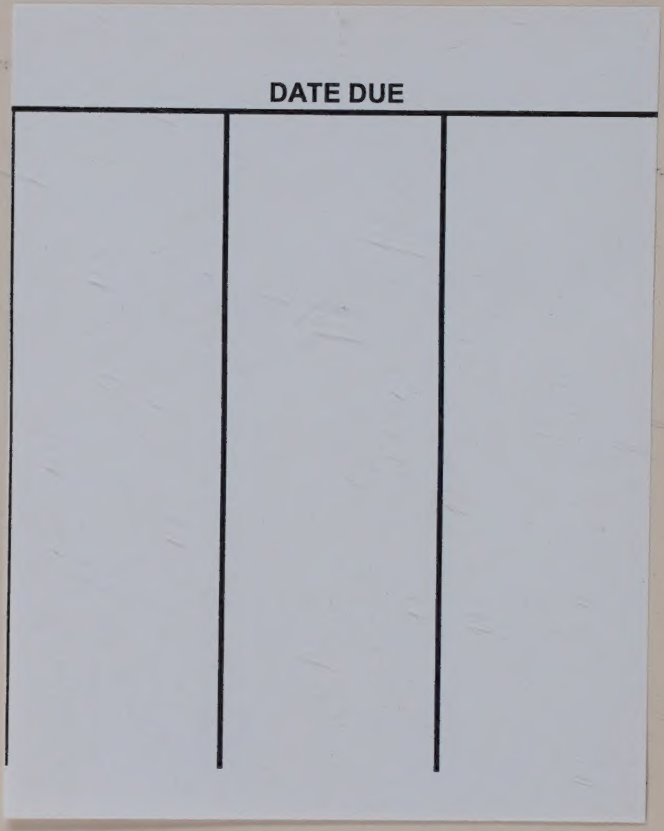
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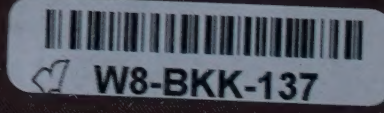
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